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RHRON: Ontario Rockfall Hazard Rating System - Field Procedures Manual

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Publication Title	**RHRON: ONTARIO ROCKFALL HAZARD RATING SYSTEM: FIELD PROCEDURES MANUAL**

Author(s)	John A. Franklin; David F. Wood; Stephen A. Senior; John A. Blair
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Ministry Contact	S. A. Senior, P. Eng. Soils and Aggregate Section, Materials Engineering and Research Office, Engineering Standards Branch, Ontario Ministry of Transportation 2nd Floor, 1201 Wilson Ave., Downsview, ON, Canada M3M 1J6 Tel: (416) 235-3743; Fax: (416) 235-4101 e-mail: stephen.senior@ontario.ca

Abstract

This Manual provides the procedures for conducting both preliminary and detailed field stability assessments of a rock slope and, if problems are identified, to assess possible remediation measures and their costs.

The Rockfall Hazard Rating System called "RHRON" described in this Manual was developed for the Province of Ontario from a previous system used by Oregon's Department of Transportation. Ontario's modified system allows Regional staff to conduct preliminary assessments, using simple field methods to determine the following four Basic RHRON, factors:

- F1 - Magnitude – "How much rock might come down?";
- F2 - Instability – "How soon is it likely to come down?";
- F3 - Reach – "What are the chances of this rock reaching the highway and how much of the highway will become blocked?"; and
- F4 - Consequences – "How severe will be the consequences of such a fall"?

Each of these four factors are rated from 0(good) to 9(bad) and when averaged together form the Basic RHRON score.

Field staff can then use the Basic RHRON score along with the so-called Crest Angle (i.e. the upward angle from the edge of pavement to the highest potentially unstable rock) to identify "Class A" rockfall hazard sites. Such sites then require a more detailed evaluation by a Rockfall Hazards Specialist using a much more comprehensive determination of the "F" factors based on individual Ratings for 20 different parameters that are fully described in this Manual.

After the detailed RHRON score is determined, then a study can also be carried out to determine the best treatment in order to mitigate whatever hazards are identified, what is the likely cost of those treatments and how effective and durable they are likely to be.

Key Words	Risk Assessment, Rockfall Hazards, Rockfall Hazard Rating, Rock Slope, Stability Assessment, Field Manual
Distribution	Unlimited public distribution to technical audience

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1201 Wilson Ave,
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This Manual provides the procedures for conducting both preliminary and detailed field stability assessments of a rock slope and, if problems are identified, to assess possible remediation measures and their costs.

The Rockfall Hazard Rating System called "RHRON" described in this Manual was developed for the Province of Ontario from a previous system used by Oregon's Department of Transportation. Ontario's modified system allows Regional staff to conduct preliminary assessments, using simple field methods to determine the following four Basic RHRON, factors:

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Each of these four factors are rated from 0(good) to 9(bad) and when averaged together form the Basic RHRON score.

Field staff can then use the Basic RHRON score along with the so-called Crest Angle (i.e. the upward angle from the edge of pavement to the highest potentially unstable rock) to identify "Class A" rockfall hazard sites. Such sites then require a more detailed evaluation by a Rockfall Hazards Specialist using a much more comprehensive determination of the "F" factors based on individual Ratings for 20 different parameters that are fully described in this Manual.

After the detailed RHRON score is determined, then a study can also be carried out to determine the best treatment in order to mitigate whatever hazards are identified, what is the likely cost of those treatments and how effective and durable they are likely to be.

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Table of Contents

Executive Summary

The Ministry of Transportation of Ontario (MTO) manages over 16,500 km of provincial highways, much of which has been blasted through the Precambrian rocks of the Canadian Shield. Many of these highways were constructed before the introduction of controlled blasting methods and, as a result, many roadside rock cuts were left highly fractured and susceptible to increased rates of weathering and erosion.

Rockfalls from such cuts generally occur seasonally and broken rock fragments are usually retained by the roadside ditches. However, some of these ditches cannot adequately catch or retain this material and some of it has occasionally been deposited onto the highway.

As a result of this, MTO developed a Rockfall Hazard Rating System called "RHRON" which can be used to conduct both preliminary and detailed assessments of the stability of such slopes throughout the Province.

The information contained in this Manual allows Regional staff to conduct preliminary assessments, using simple field methods, in order to determine a slope hazard rating based on the following RHRON "F" factors:

F1 - Magnitude – "How much rock might come down?";
F2 - Instability – "How soon is it likely to come down?";
F3 - Reach – "What are the chances of this rock reaching the highway and how much of the highway will become blocked?"; and
F4 - Consequences – "How severe will be the consequences of such a fall"?

Each of these factors has a scale from 0(good) to 9(bad) and when averaged together forms the Basic RHRON score. This score, along with the so-called Crest Angle (i.e. the upward angle from the edge of pavement to the highest potentially unstable rock), allows Regional staff to identify "Class A" rockfall hazard sites.

Class "A" sites then require a more detailed evaluation by a Rockfall Hazards Specialist using a more comprehensive determination of the "F" factors based on individual Ratings for 20 different parameters that are fully described in this Manual.

The Manual also describes methods that can be used to determine the best treatments in order to mitigate whatever hazards are identified, what is the likely cost of those treatments and how effective and durable they are likely to be.

Copies of the Manual and the ®MSExcel spreadsheet used for processing the RHRON data can be respectively obtained from the following MTO webpage under *Manuals* and *Forms*:

https://www.raqsb.mto.gov.on.ca/login/raqs.nsf/English/Graphic/ViewConstructionDocs?OpenForm

1.0 Introduction

1.1 THE NEED FOR HAZARD PRIORITIZATION

The Ministry of Transportation of Ontario (MTO) manages over 16,500 km of provincial highways, much of which has been blasted through the Precambrian rocks of the Canadian Shield. Many of these highways were constructed before the introduction of controlled blasting methods when the goal was to achieve maximum fragmentation of rock with little regard to preserving the structural integrity of rock that was left behind. As a result, many roadside rock cuts are fractured and susceptible to increased rates of weathering and erosion. Rockfalls occur seasonally and broken rock fragments are retained mostly by the roadside ditches. However, ditches are primarily designed to carry water and store snow, not to catch falling rock. As a result, some rockfall material has occasionally been deposited onto the highway.

Rockfalls that overspill the ditch are usually reported within hours by maintenance personnel and then cleared the same day. This is probably why there have been relatively few rockfall-related accidents. Rockfalls remain far down on the list of the causes of accidents when compared, for example, with collisions involving animals, icy conditions or impaired driving.

Given the variety of diagnostic, preventative and protective treatments that are available today, one can argue that most rockfall hazards might have been recognized and even the few accidents that have occurred could have been avoided. However, with limited resources, it was recognized some form of prioritization was needed to ensure that the funds that are available are allocated in a systematic and cost-effective manner. With this in mind, MTO convened a task force in 1992 that produced a Rock Slope Hazards Management Program which was designed to systematically identify, prioritize and remediate rockfall hazards.

1.2 THE ROCKFALL HAZARD RATING SYSTEM

1.2.1 DEVELOPMENT OF RHRON

The Rockfall Hazard Rating System for Ontario (RHRON) was developed to assist in assigning treatment priorities. It is based on a Rockfall Hazard Rating System (RHRS) developed by the Oregon Department of Transportation (Pierson et al., 1990). However, some major revisions were made to the RHRS to adapt it for use in Ontario (Franklin and Senior, 1997a). The detailed version of RHRON is based on twenty(20) parameters rather than the twelve in the Oregon system. Added observations include such fundamentals as the height of the water table emerging from the rock face, the looseness of the rock face and the block size of the rock mass. All of the parameters are estimated on a rating scale from 0 = "good" to 9 = "bad".

Most of the individual ratings that make up the RHRON system can be estimated in a few minutes and, with a two-person team, sites can be fully documented in about 30 minutes. This includes a detailed evaluation of the hazard rating as well as a preliminary assessment of remediation measures and costs.

Some of the ratings are determined directly, while others are determined through simple computations. However, all formulae are stored and handled on ®MS Excel spreadsheets so no inordinate demands are placed on the time or memory of the inspectors. Field guide charts provide a full list of the RHRON equations and conversion tables that are needed.

1.2.2 COMPOSITION OF RHRON

There are two versions of RHRON – basic and detailed. The "Basic RHRON" is used for Preliminary Screening for rockfall hazards and it is obtained by answering four simple questions relating to "Factors" F1 through F4:

F1 Magnitude: "How much rock might come down?"

F2 Instability: "How soon or often is it likely to come down?"

F3 Reach: "What are the chances of this rock reaching the highway and how much of the highway will become blocked?" and

F4 Consequences: "How severe will be the consequences of any such fall?"

For consistent and rapid recording of responses to these and subsequent more detailed questions, each answer is rated on a scale from 0 (good) to 9 (bad). The four factor ratings are averaged to obtain the Basic RHRON score, also on a scale of 0 to 9.

$$RHRON = (F1+F2+F3+F4)/4$$

Preliminary Screening uses a combination of Basic RHRON and Crest Angle, one of the most important and least subjective RHRON parameters, to arrive at the identification of "Class A" rockfall hazard sites that require a Detailed Evaluation by a rockfall hazards' specialist. In this subsequent evaluation phase for higher priority sites, the definition of RHRON is unchanged but each of the four factors is obtained by averaging a larger number of parameter ratings to determine the "Detailed RHRON".

1.2.3 COST AND COST-BENEFIT

Although not included as part of the actual rockfall hazard rating, three further fundamental questions must be asked in order to complete the evaluation of the hazard site:

F5 Treatment: "How can the hazard best be mitigated?"

F6 Cost: "What is the likely cost of this treatment?" and

F7 Effectiveness: "How effective and durable is the treatment?"

RHRON is combined with a preliminary cost estimate of the remedial treatment(s) to give COSTBEN, a cost-benefit ratio. The "cost" is estimated from construction unit rates together with estimated quantities for each segment of the rock face. The "benefit" is then

assessed from the estimated reduction in hazard which is achieved by the proposed treatment(s). As you would expect, COSTBEN is relatively high for small sites requiring limited treatment.

1.2.4 TERMS AND SYMBOLS

An index of the RHRON terminology and the abbreviations that used in this Manual are given in Appendix 1. The following standardized notation is used for the terms on which RHRON is based:

Parameter (P): means a property characterizing the degree of hazard.

Value (V): means the numerical value of the parameter, with units of measurement.

Truncated Value (T): means a Value cut off at its upper and/or lower limits if it cannot exist outside a specified range.

Rating (R): means a Value or Truncated Value converted to a standard range from 0 (good) to 9 (bad) for purposes of comparison and combination.

Factor (F): means a major component of RHRON obtained by averaging a group of related Ratings.

As an example, P2 Qmax is defined as the volume of the largest expected rockfall or slide. Values for V2 range from zero to several million cubic metres in mountainous regions, but are truncated to T2 (1 to 10 m^3) for rating purposes. The rating R2 ranges from zero for Qmax = 1 m^3 up to 9 for Qmax = 10 m^3. R2 contributes to the F1 “magnitude factor” which is defined for the Detailed Evaluation as (R2 + R3 + R12)/3.

The basic composition of RHRON is presented in Figure 1 of this Manual.

1.3 STRUCTURE OF THE MANUAL

This manual is intended to provide field inspectors with the information needed to successfully use RHRON.

Preparations for the Fieldwork and the materials required are presented in Section 2;
Preliminary Screening procedures are described in Section 3;
Detailed Evaluation rating, treatment and cost estimation procedures are presented in Section 4; and
Further technical background, for example, criteria for selection of remedial treatment(s) is discussed in Section 5.

Appendix 1 contains a listing of the Terms and Abbreviations used in this Manual;
Appendix 2 contains all of the Figures that are referred to; and
Appendix 3 presents an Alternative Determination of Crest Angle.

Copies of this Manual and the ®MSExcel spreadsheet used for processing the RHRON data can be respectively obtained from the following MTO webpage under *Manuals* and *Forms*:

https://www.raqsb.mto.gov.on.ca/login/raqs.nsf/English/Graphic/ViewConstructionDocs?OpenForm

2.0 Preparations for Fieldwork

2.1 PREQUALIFICATION

Before undertaking any rockfall hazard rating fieldwork, all personnel shall be pre-qualified with regard to both safety and all technical aspects. For rockfall inspection work, two levels of qualification apply:

For Preliminary Screening, inspectors must be familiar with the preliminary screening and site classification procedures (Section 3) described in this Manual; be proficient at identifying rockfall and slide mechanisms and rock instability; and be able to measure and assess crest angle and rockfall reach.

For Detailed Evaluations, remediation design and costing, inspectors are required to have qualifications in geological engineering or related disciplines and considerable experience in slope stability studies and assessment of rockfall hazards. They must also be familiar with all of the RHRON procedures (Section 4) described in this Manual.

Prequalification can be scheduled as an initial phase of a hazard rating contract and will require personnel to complete RHRON ratings on one or several rock faces that have been previously rated. "Practice sites" can be provided, as well as examples of previously completed data sheets for those sites. Consultants currently approved to conduct RHRON hazard ratings can be obtained from the following MTO webpage using the Foundation Engineering Category – *Rock Slope Hazard – Medium Complexity* specialty for preliminary screening or *Rock Slope Hazard – High Complexity* specialty for detailed ratings:

https://www.raqsb.mto.gov.on.ca/login/raqs.nsf/English/Graphic/frmViewApprovedConsultants?OpenForm&Start=1&Count=1000&Expand=2.7&Seq=4

Responsibilities

All field data sheets are to be signed and dated by the inspector on the understanding that the information that is provided is only used for purposes of hazard assessment and prioritization of sites. The methods proposed for remediation and the cost estimates may be re-evaluated in a detailed design study. It should be expected that any such detailed investigation may result in substantial modifications to the design.

MTO Liaison

Inspectors should make appointments with maintenance personnel who are available for a site reconnaissance. The maintenance personnel can introduce inspectors to locations where persistent rockfalls and/or accidents have occurred along their patrol routes. As well as being helpful in locating the more important hazard locations, such information is specifically required in order to evaluate P1 "Rockfall History" (Section 5.2). The introductory site reconnaissance should be split into sections corresponding to highway patrol routes and should not be combined with actual hazard ratings because of time and

scheduling limitations.

2.2 LOCATING AND IDENTIFYING SITES

2.2.1 MAPS AND DOCUMENTATION

The route should be planned and base maps prepared using 1:50,000 scale topographic maps. Digital maps at this scale are available for all locations in Ontario.

It is generally advisable to study published information on variations in geological conditions, rock character and stability within the study area, before setting out. Topographic contours are useful for terrain evaluation and air photo coverage is available for most locations.

2.2.2 LHRS SYSTEM

MTO traditionally locates its sites using the Linear Highway Reference System (LHRS) which includes "Base Points" and "Offset". The appropriate base points and offsets can be obtained from the applicable MTO Region. Details can also be found at the following webpage:

http://portal.mto.ad.gov.on.ca/sites/MTO/PHM/HSB/go/WebSiteOnly/F_LHRS.aspx

A base point may be a Township, MTO District or OPP District boundary, major road intersection, bridge, etc. Offsets are measured in kilometres by a vehicle's odometer ("trip meter") from the base points. However, the evaluator should be aware that some roads cross the same river in more than one spot. So when other types of landmark are used as LHRS base points, make sure that all can be located before setting out. This system produces a relative location from a known base point.

When feasible, drive each section of highway from south to north or from east to west in the direction of increasing LHRS numbers. Record each major intersection along the route and re-zero the trip meter at each base point. Avoid recording offsets greater than 10 km without a reliable check landmark along the way. Complete each route log by "closing" on an intersection beyond the last hazard. Even with these precautions, location errors are likely.

The site location corresponds to the "start point" of lowest LHRS at the eastern or southern end of the hazard rock face. Where hazards exist on more than one side of a highway (potentially at several locations on divided highways with entry and exit ramps), each should be assigned a different site number and LHRS coordinates.

2.2.3 GLOBAL POSITIONING SYSTEM

All Class A and B sites shall be located using a Global Positioning System (GPS, set with UTM Coordinate Grid, NAD83 datum) and their coordinates plotted on 1:50,000 scale site location maps that were prepared during preliminary screening and provided to those performing the detailed evaluation. This system produces an absolute location independent

of other features.

The site location corresponds to the eastern or southern end of the hazard rock face. Where hazards exist on more than one side of a highway (potentially at several locations on divided highways with entry and exit ramps), each should be assigned a different site number and GPS coordinates.

2.2.4 SITE NUMBERING

Class A rockfall hazard sites shall be identified by a unique and unambiguous site letter-number designation. MTO personnel from the Regional Office will assist with site numbering. The site number should be recorded on the rock face on a dry and flat location in figures approximately 300 to 400 mm high, as high on the face as practicable, and in yellow or white paint. The number should be included in photographs as well as on maintenance and inspection reports. It is suggested that each district have its own letter designation and allocate batches of unused numbers for each new inspection contract. Gaps in sequence are unimportant provided that numbers are not duplicated.

It is recommended that recorded numbers include reference to the MTO Region as well as highway number. For example, "NE-17-L24" would refer to a site identified as L24 on the rock face alongside Highway 17 within Northeastern Region.

2.2.5 FIELD EQUIPMENT

Figure 2 gives suggestions for a field equipment checklist. Several of the items are optional and others may need to be added or modified.

3.0 Preliminary Screening

3.1 ROCKFALL HAZARD LOGGING AND SITE CLASSIFICATION

3.1.1 TERMS OF REFERENCE

The Preliminary Screening phase includes compilation of a Highway Rockfall Hazards Log (Figure 3); completion of Preliminary Screening forms for Class A and B sites (Figure 4); categorization of sites into Class A, B or C according to crest angle and RHRON (Figure 5); and marking Class A site locations and site numbers on the rock face and on base maps.

3.1.1.1 CRITERIA FOR SITE CLASSIFICATION

Sites are classified into Class A, B or C according to where they plot on the Basic RHRON hazard rating diagram shown in Figure 5. The diagram is divided into three active zones plus a triangular inactive zone in which no sites can plot. Step-by-step procedures for site classification are given below.

Crest angle or Cang is an important element of both preliminary and detailed site evaluation. It is defined (see Figure 6) as the upward angle from EOP (Edge of Pavement) to the highest potentially unstable rock. Conservatively this is usually taken as the crest of the cut slope. For a vertical rock face Cang is the angle whose tangent is slope height divided by clear zone width, Czw (i.e. the combined width of ditch and shoulder). Crest angle therefore reflects the adequacy of the ditch, for any given height of rock face. It is the main parameter for assessing the "reach" of falling rock fragments.

Most Class C sites can be checked from a vehicle and cleared as not requiring an on-foot inspection. The main criterion is very low reach potential. Class C sites have crest angles less than 33° and, although they may be unstable, there is no significant possibility of any part of a potential fall or slide reaching the travelled portion of the highway. These are considered low rockfall hazard sites.

Class B sites require an on-foot inspection. They have crest angles in the range of 33° to 60°. On the basis of combined Basic RHRON and measurements of crest angle they are cleared as being moderate rockfall hazard sites which do not require a detailed evaluation.

Class A sites include all those with crest angles greater than 60° as well as any others classified using the class boundary equations or plotting basic RHRON and Cang on Figure 5. These high rockfall hazard sites will require a follow-up detailed evaluation by an MTO-designated rockfall hazard specialist.

The inspector's judgement can over-rule class boundaries in order to downgrade or upgrade a site (i.e. for instance from Class B to C or from Class B to A, respectively). This may be necessary in cases where a hazard requires special assessment, such as in a toppling failure

where rotation about the base of a high slab may deposit rock onto the travelled part of the highway. Other special cases can include potential rolling blocks with "launching features" projecting from the rock face. If in doubt, always call for a second opinion by designating the site as Class A.

3.1.2 TECHNIQUES FOR PRELIMINARY SCREENING

3.1.2.1 Hazard Logging from a Vehicle

The object is to assemble an inventory of the rock cuts along the highway, recording all non-hazard as well hazard sites. Start the log, on a form such as that shown in Figure 3, by recording the highway number. Identify the LHRS base point in column 5 and reset the trip odometer to zero at this location. Be aware that using LHRS and offset requires cumulative distances that are accurately measured from one LHRS base point to another. This probably means that you cannot back up or turn around.

On approaching a potentially hazardous site, slow to about 20 km/h with warning lights flashing and drive close to the shoulder. Ignore rock outcrops with crest angles (i.e. Cang) of less than 20°. For all sites with Cang in the range of 20-33°, record a "C" in the second last column (i.e. "Hazard Class") of the log and the corresponding trip odometer reading (i.e. "Offset") in column 6. Stop at or near all potential Class A or B sites. For an on-foot inspection, park the vehicle at a safe location "upstream" of the hazard, if possible.

If necessary, drive the highway a second time in the same direction to log hazard sites on the opposite side of the lane or lanes. In this case, separate log entries will be required for the "Left" or "Median" and the "Right" or "Outside" sides of the lane or lanes in each direction. Divided highways with up to four rock faces at any one location may require up to four passes and separate log sheets should be filled out for each direction.

3.1.2.2 On-foot Inspection

First check whether the site can be designated as Class C without measuring RHRON. This is the case for all sites with crest angles less than 33°. Borderline Class B or C sites can be classified as C, if on close examination they involve small quantities of rock or appear stable. Take into account whether traffic is light and fragments spilling onto the pavement would be visible from distances in excess of 200 m. In such cases, record a "C" on the log; make a note in the last (i.e."Remarks") column that the site has been inspected on foot and proceed to the next site.

Sites with crest angles greater than 60° are considered Class A regardless of their values of RHRON. Nevertheless, basic RHRON assessment is required to establish hazard priorities for interim treatment where follow-up inspection may be delayed and to identify those sites that represent an immediate hazard and require the most urgent remediation. Basic RHRON observations for all sites with Cang greater than 33° should be completed as described below.

3.1.3 PROCEDURE FOR ESTIMATING BASIC RHRON

Using a Preliminary Screening data collection form such as that shown in Figure 4 and

before leaving the vehicle, fill in the Highway #, Site #, Side, Direction of Lane(s) if applicable), Base Point LHRS, Offset Distance, and any Warning Signs. The next part of the procedure must be done with great care since it involves crossing the highway. Measure the crest angles B and A, clear zone width Czw, and roadway width X. Evaluate the potential failure mechanism(s), then estimate or measure the values for the four factors, F1 through F4, described in subsection 3.1.3.2. Take digital images of any high hazard sites. Add comments relating to specific features, previous rockfalls, utilities etc. then use a laptop computer to calculate Cang and Basic RHRON. Complete the Preliminary Screening form and the Highway Rockfall Hazards Log with GPS coordinates before you leave the site.

3.1.3.1 Determination of Crest Angle

The most likely scenario for the determination of the crest angle involves measuring two angles and up to three distances, as shown in Figure 6. These variables are combined with the fixed distance for the height of the instrument so that various calculations can be made to evaluate Cang.

From the farside EOP, measure angle B and possibly take an overall digital image of the site. Then cross the highway to the nearside EOP, and measure the roadway width X. Measure angle A and the slope distance S_A. Measure the clear zone width Czw, then record all of the measurements on the form shown in Figure 4.

Transfer the recorded data to a laptop computer in the vehicle and compute Cang, which is then recorded under the F3 column in the form. Then the remaining Basic RHRON calculations should be completed and recorded.

Once all of the information has been recorded, an evaluation must be made to determine the rockfall hazard classification. This can be done using the chart shown in Figure 5.

Average the four factor scores to obtain the Basic RHRON. This can all be done automatically in the spreadsheet. The resulting interpretations of Rockfall Hazard Class are then added to the RHRON Highway Rockfall Hazards Log shown in Figure 3.

3.1.3.2 Basic RHRON Factors

F1 Magnitude: For ravelling rock faces, estimate the total in-place quantity "Qtot" of loose rock that would be removed if the face were to be scaled with a backhoe excavator under "normal" machine scaling. However, where the potential instability is by sliding, estimate the total volume of slide material that you would expect to come down in a 20 year period. Note the volume in cubic metres in the F1 column of the form shown in Figure 4 and convert this volume to a rating.

F2 Instability: Estimate the instability F2 based on the frequency or risk of rockfalls at this location. Take into account face looseness and open jointing as well as any obvious evidence of previous falls such as rock in the ditch, fresh or unweathered faces on the rock cut or scars on the asphalt. Consider the condition of the rock, particularly the closeness, persistence and strength of jointing and any signs of a high water table with poor drainage or groundwater seeping from the face. Take into account whether the face has recently undergone a thorough mechanical scaling. Circle the instability frequency in the F2 column and convert this to a rating.

F3 Reach: Base your estimate of reach potential on crest angle. Measurements of the apparent crest angles A and B and other slope geometry parameters have been recorded in the Preliminary Screening form. Use the spreadsheet to calculate Cang, then circle the value for the F3 parameter to obtain a rating.

F4 Consequences: This relates to the probability of a rock on the highway causing an accident. Use published AADT values to represent traffic density as the first part of F4. Measure the distance that approaching cars would first see a rock on the pavement with a laser range finder. Circle the values for the two F4 components and then convert them to ratings. In marginal cases, consider the adequacy of warning signs and the space available for vehicles to avoid obstructions.

3.1.4 COMPLETING THE PRELIMINARY SCREENING

For those sites designated Class A, allocate a site identification number, mark it on the rock face, see section 2.2.4 above, record it in the form, on the Hazards Log and on a site location map (i.e. this may be carried out later using GPS mapping software). Record Class A and B site locations using a GPS and complete the record of digital images. Class C sites are identified by their LHRS location only.

Note the type of instability and any comments such as "rock in ditch" or "site on a sharp bend, in the lines that are designated for "Comments" in the Preliminary Screening form. Make sure all log entries are complete and legible. Sign and date the form then transfer the appropriate information to the Highway Rockfall Hazards Log form shown in Figure 3.

4.0 Detailed Evaluation

4.1 TERMS OF REFERENCE

All Class A sites are to be given a detailed inspection and hazard rating. This phase includes: identifying potential instability mechanisms; providing RHRON hazard ratings for each site; advising on remedial treatments and their cost; and providing photographic documentation of the hazards.

Detailed RHRON field data sheets are double-sided. Side 1, shown in Figure 7, records the geometry of the face, hazard mechanisms, treatments and costs. Side 2, shown in Figure 7, records the hazard rating data. Complete Side 1 first in order to select the most hazardous segment for the detailed rating.

4.2 SEGMENTATION AND MARKING OUT

4.2.1 SEGMENTS

Hazard segments are lengths along the rock face in which the type of instability and degree of hazard are more or less constant. Avoid averaging stable and unstable sections of the face. Only segments with near-identical slope heights, ditch conditions, failure modes, hazard ratings and proposed treatments should be grouped together. Usually one to three segments are sufficient. All other columns should be left blank. For rock cuts greater than approximately 150 metres long, it may be convenient to divide the cut into 25 metre segments to aid in the data collection process.

4.2.2 SITE OVERVIEW

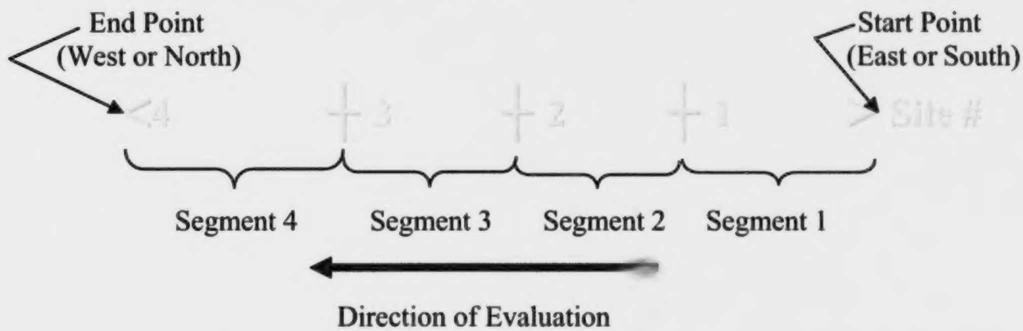
Since detailed evaluation involves crossing the highway a few times (i.e. usually twice per hazard segment,) safety is of paramount importance.

Park the vehicle clear of the travelled portion of the highway, “upstream” of the Class A rock cut. Use four-way flashers and a 360 degree rotating beacon. Make an initial assessment of variations in crest height, types and degrees of instability. Decide how many segments are needed and where their end points should be. From the farside and nearside shoulders, view the rock face, from both ends and from the crest (if accessible). This will allow open joints and other features to be observed that may be hidden when viewing from one or another direction. Binoculars can assist in examining high sections of the face or loose talus, boulders or scarps high on the natural upslope. Also note any rock in the ditch, fresh or unweathered faces on the rock cut or scars on the pavement, as well as the presence, type and location of any utilities. Place temporary marker cones or flags and adjust them until you have optimized the limits of segments. The end points of the overall site should coincide

with the start and end of the first and last hazard segment. The segments, including hazardous and non-hazardous sections, should be continuous and have no gaps.

4.2.3 MARKING OUT AND MEASURING

Starting at the east or south end of the hazard site (lowest LHRS number), paint the site number, segment numbers and their start and end points on the rock face using similar notation as in the following example showing 4 hazard segments:



Spray-paint the symbols in yellow on dry sections of the rock face about 1.5 m above EOP level. Incorrect markings should be removed, or over-painted in a colour similar to that of the rock.

4.3 SIDE 1 DATA SHEET

Use a measuring wheel to determine the start and end distances for each segment. Alternatively, for construction projects, refer to and record the project stationing marked on the right shoulder. The 25 metre marks may also be used to 'calibrate' the inspector's stride, which may be accurate enough. Record the values to the nearest metre and subtract to give the segment lengths. Place a fully extended ranging pole against the rock face in the middle of the first segment; cross the highway to take a digital image of the overall cut and a detailed photo of the first segment. Estimate the overall height of the segment relative to the ranging pole and record this value. Measure the farside crest angle B with a clinometer, then cross back to the rock cut to measure the nearside crest angle A and measure the distance X between them. Alternatively, the slope distance S_A may be measured using a laser range finder. Record the details of mechanisms, dimensions and treatments and take additional close-up images of specific features, if required. Complete the recording for the first segment by measuring the clear zone width and the available paved width of the highway which can conveniently be done using the ranging pole.

Repeat this procedure for all segments, then determine which has the most severe hazard for the reverse side of the form. The following information is to be recorded.

4.3.1 ROCKFALL TYPE AND QUANTITY

4.3.1.1 Mechanisms

Record S(stable segment), A(adequate catchment) for a segment where no falls could reach the pavement, or the letter designations R(ravelling), O(overhang collapse), I(ice jacking), B(bouncing/rolling block fall), W(2-D wedge slide), P(pyramid 3-D wedge slide), or T(toppling), of up to three instability mechanisms in a sequence corresponding to their estimated degree of hazard. For example, "WO" indicates a 2-D wedge slide with secondary overhang collapse potential.

4.3.2 TOTAL QUANTITY OF POTENTIAL ROCKFALLS (QTOT AND ΣQTOT)

For each segment, visually estimate and then record the total quantity of potential falls/slides Qtot. Qtot is defined as the in-place volume that would be removed if the face were to be scaled (with careful machine scaling), or in the case of a slide, the total that you would expect to come down in a 20 year period as a result of natural weathering, earthquakes etc. ΣQtot is the sum of Qtot for all segments.

4.3.3 HEIGHT

For each segment, estimate the height (i.e. upper limit of potential instability above EOP.) Estimated heights are used in combination with measured values so that a more accurate evaluation of height can be made. In most cases, the face will be inclined and determining the height using clinometer measurements from both the nearside and farside EOP, as shown in Figure 6 b) will be required. If the slope distance S_A is determined using a rangefinder, then Cang can be alternatively calculated using the following equation:

$$\text{Cang} = Tan^{-1}\left[Tan\,A + \frac{HI}{S_A\,Cos\,A}\right]$$

The height is normally the vertical height of a near-vertical face. In the case of an inclined face or one with an unstable upslope, height is the elevation difference between the nearside EOP and the highest potentially unstable rock. This may include all or part of any natural slope up to the maximum height that is visible from the highway and the blasted cut face.

4.3.4 CREST ANGLE (CANG) AND CLEAR ZONE WIDTH (CZW)

Measure the clear zone width Czw, which is the horizontal distance from EOP to the rock face and includes the combined width of ditch and shoulder. When it's safe to do so, stand on the EOP and measure the crest angles A and B to the upper limit of instability using a clinometer and then measure the slope distance S with a laser range finder. Calculate Cang on a laptop computer running in the vehicle using the equations from Figure 6.

4.3.5 TOTAL HAZARD LENGTH (ΣLHAZ)

Add the lengths of hazardous segments (those without a stable "S" or adequate catch "A" designation) to obtain the total hazard length, ΣLhaz.

4.3.6 LARGEST EXPECTED FALL (QMAX)

Estimate the in-place volume of the largest and most hazardous expected single rockfall or slide event, Qmax.

4.3.7 WORST HAZARD SEGMENT

Determine the worst hazard segment as a function of Qmax, Height, Cang and Czw, the degree of instability and the likely impact on the highway (factors F1 and F4). Circle the segment number, then copy its values for Qmax, Height, Cang and Czw in the right hand boxes for V2, V12, V13 and V14. It's possible that Qmax may be smaller than Qtot for the segment, such as when loose rock is ravelling piece by piece as individual boulders or progressive failure. It can also be smaller than other events on site when these are less likely to occur or to reach the highway. If the most hazardous segment is still in question, then determine the Basic RHRON for more than one segment and select the worst (i.e. highest) value. Values for these parameters are also transferred to Side 2 of the Detailed Evaluation form, shown in Figure 7.

4.3.8 REMEDIATION MEASURES AND COST ESTIMATES

After examining the condition of each segment in detail, make an overall assessment of the most cost-effective, permanent approach to remediation for the site as a whole.

4.3.9 SELECTION OF TREATMENTS

Selecting an appropriate combination of treatments and estimating their likely cost is at least as much of a challenge as determining a hazard rating. You need to take into account: applicability to conditions on site; local availability of materials and skilled personnel; the durability of treatments; risks and side effects; as well as aesthetic and environmental aspects. Some of the above are reviewed in Section 5 of this Manual. Inspectors engaged in detailed hazard rating will be well aware of the broad literature on this topic.

The "remediation" part of the field data sheet has been grouped into four sections relating to the four hazard factors. It is important to make a link between the type of treatment and the objective of, for example, trying to reduce:

F1 "Magnitude" by removing or reducing the height of the hazard by machine scaling or trim blasting;

F2 "Instability" by shotcreting, anchoring or draining the slope;

F3 "Reach" by improving catchment facilities; installing mesh etc.; and/or

F4 "Consequences" by installing monitoring alarms, improving lighting, lowering speed limits and/or posting warning signs to lessen the potential hazard represented by rock ending up on the pavement.

4.3.9.1 Single Treatment Combination

It is most common to specify removal of the hazard using a combination of machine scaling, trim blasting and controlled blasting with careful reinstatement of the ditch for rockfall catchment. Select one treatment combination as a basis for cost estimation, in order to provide a uniform remediation plan that will allow consistent prioritization of sites with a view to cost as well as degree of hazard. Alternative approaches can be suggested in the "Notes" at the foot of the data sheet or on a separate attached sheet.

4.3.10 QUANTITIES AND COSTS (COST AND COSTNET)

Record the estimated quantities for each type of treatment at each hazard segment, then add each of them together to obtain the total quantities for the site as a whole. The process of multiplying by the unit price to obtain the total cost (i.e. for all segments) for each type of treatment, then adding these subtotals to obtain "Costnet" is usually carried out later. It should be noted that the Ministry can provide average unit costs from previous projects (available from the MTO's Highway Costing System, HICO) to assist in the estimates. However, it should be noted that the range of contract unit prices has recently been very high.

4.3.11 CONTINGENCY ALLOWANCE (CONTINGE)

Estimate and record "Continge" which is the ratio of anticipated total contract cost divided by Costnet. A standard allowance of 1.5 is recommended. If the overhead costs are expected to be unusually high (small contracts, difficult access or working conditions), then a multiplier of up to 2.5 can be specified.

The "Continge" multiplier includes adjustments for items such as: consulting fees for follow-up investigations and design; preparation of specifications and contract documents; supervision of the work; quality control testing; the Contractor's mark up for mobilization; escalations caused by uncertainties in the extent of treatment; budget overruns; claims etc. It can also include an allowance for differences between the standard unit prices listed on the field data sheet and those likely to apply locally. An appropriate range of values can be determined in advance of the fieldwork or after its completion by comparing estimates with final contract costs for a range of simple to complex contracts.

4.3.12 REMEDIATION COST (REMCOST)

Calculate "Remcost" (i.e. the gross estimated remediation cost), by multiplying Costnet by Continge. Remcost is an actual dollar amount which can be used as an approximate guide for budgetary allocations. For prioritization purposes, a rating is also calculated on a logarithmic scale which gives the order of magnitude of estimated cost.

4.3.13 REMEDIATION EFFECTIVENESS INDEXES (REMX1 TO REMX4 AND ΣREMX)

ΣRemx measures the anticipated success of the total treatment combination.

A standard value of 90% is allocated for ΣRemx where a treatment is deemed to be so effective a remedy as to preclude long-term maintenance costs and repeat treatments at least for the next 20 years. Alternatively, estimate and record ΣRemx then divide this into components Remx1 through Remx4 reflecting the individual contributions of each category of treatment. A Remx of 100% in any one category indicates that the treatment in this category alone would be sufficient to entirely and permanently remove the hazard.

The data on Remcost and ΣRemx are then transferred to Side 1 of the data sheet, shown in Figure 7, where they are combined with the RHRON hazard rating to calculate the cost-benefit ratio, "COSTBEN".

4.3.14 INSPECTOR'S NOTES

Draw attention to any special features of the site, the urgency of treatment, the need for any follow-up studies, potential alternative approaches to remediation, reasons for selecting the preferred treatments and their probability of success.

4.4 SIDE 2 DATA SHEET

Side 1 of the field data sheet should be completed first in order to select the "worst hazard segment". Once it has been selected, return to that hazard segment to observe and record the ratings that contribute to the Detailed RHRON score.

The field data sheet contains columns to record both the value of the parameter and the corresponding rating on a scale from 0 "good" to 9 "bad". The ratings for parameters 1, 5 and 6 are directly estimated. However, for all other parameters, a numerical value is recorded and then a rating is determined from that. The rating bar scales provide a convenient visual check on the relative contributions of each parameter to the overall degree of hazard.

A conversion table is provided in Figure 8 to assist in field estimation of ratings from Values. Alternatively, the ratings can be determined using the spreadsheet after completing the day's fieldwork. The equations that are employed by the ®MSExcel spreadsheet to determine the ratings are summarized in Figure 9.

Where numerical values are entered, the spreadsheet will automatically calculate the ratings.

4.4.1 ROCKFALL HISTORY AND QUANTITIES

4.4.1.1 History of Falls (P1)

Rockfall history (activity) is estimated from site observations such rock in adjacent ditches, fresh, unweathered faces on the rock slope or pock marks in the adjacent pavement as well as maintenance and accident reports (including interviews with maintenance personnel). The rating is directly estimated.

4.4.1.2 Rockfall Quantities, Qmax (P2) and ΣQtot (P3)

Carry forward the values for these parameters from Side 1 of the data sheet. The ratings can then be calculated using the spreadsheet.

4.4.2 FACE CONDITION

4.4.2.1 Face Irregularity, Firr (P4)

Estimate Face Irregularity Firr in metres based on the descriptive scale shown in Figure 10, noting that the truncated value of Firr ranges from 0 to 2.5 metres. The irregularity may be caused by erosion, ravelling or blast overbreak. The assessment is based on three criteria, "percent half-barrels", "average thickness of shotcrete required", and "maximum depth of overhangs/undercuts". Estimate the rating based on these three criteria.

Where "half barrels" (blast hole traces) remain, the total visible length is expressed as a percentage of length drilled. The % half barrels index Hbr, is a measure of blast overbreak and face smoothness. Hbr values of 100%, 80%, 60%, 40% and 20% define R4 = 0, 1, 2, 3, and 4 at the smooth end of the Firr rating scale.

The central part of the scale (R4 = 4, 5, and 6) is defined mainly in terms of the average thickness of shotcrete "Shot (cm)" that would be needed to produce a locally smooth and stable face. It is about one-half of the average crest-to-trough amplitude of the face.

The rough end of the scale (R4 = 7, 8, and 9) is determined primarily by the horizontal projection distance of major "launching features" (LF, m) and/or overhangs (Ohg, m) or undercuts (Uct, m).

4.4.2.2 Face Looseness, Loose (P5)

According to Figure 11, face looseness is determined in terms of the number of open joints visible in the face, their typical apertures and an assessment of how easily the rock can be scaled by machine or by hand. Face looseness is recorded directly as a rating.

4.4.3 ROCK MASS PROPERTIES

These include intact rock material characteristics and properties of discontinuities, including all types of weakness planes such as faults, shears, bedding planes, foliation schistosity and cleavage, in addition to joints or natural fractures in the rock mass. When estimating jointing

properties for purposes of hazard rating, choose a "worst representative joint" such as a potential surface of sliding.

4.4.3.1 Joint Orientation/Persistence, Jop (P6)

The joint orientation/persistence rating is defined in terms of the trace length (persistence or continuity) and orientation of the worst joint or joint set. Directly estimate the rating using Figure 12 as a guide.

4.4.3.2 Intact Strength, UCS (P7)

The intact strength of the rock material (excluding the weakening effect of joints) is represented by the Uniaxial Compressive Strength (UCS). Estimate UCS from the descriptive table shown in Figure 13(a). For rocks, strengths generally range from < 0.50 to 250 MPa. However, the range shown in Figure 13 (a) is further extended down to 25 kPa for weak joint filling materials. Supplementary testing (i.e. with either UCS tests or the simpler point-load strength tests) is recommended only when the weakness of the rock material is considered to be a significant factor contributing to instability. It should be noted, however, this is not usually the case in the Canadian Shield.

4.4.3.3 Shear Strength, Phip (P8)

Joint shear strength is represented by the parameter Phip which is also employed in sliding stability calculations (Maksimovic, 1996). When Phip is required only for hazard rating purposes, record the approximate value from Figure 13(b). It should be noted that, for ravelling failures, which is the most common mode of failure in the Canadian Shield rock masses of MTO's Northeastern and Northwestern Regions, the detailed evaluation of RHRON is insensitive to uniaxial compressive strength and shear strength. If planar sliding is the dominant mode of failure, supplementary jointing data, should be collected (see Appendix 3 for details).

4.4.3.4 Block Size, Block (P9)

Block size is defined as the average linear dimension (cm units) of a typical block in the rock face. For rapid estimation, visually select a typical block and estimate its average dimension. It may also be useful to evaluate the size of rock blocks that have already fallen into adjacent ditches.

When block size data is also required for bouncing and rolling calculations or for catch fence design, more accurate measurements can be made by conducting scanline measurements along the rock face or by taking scaled measurements from photographs. For scanline analysis, affix a tape measure to the rockface, keeping it as straight and taught as practicable. Count the number of joints "N" that are intersected along the length "L of the tape measure. The block size is given by 100L/(N-1), where L is in metres.

Since block size occupies a logarithmic scale, ranging from 2 cm (R = 9) to 2 m (R = 0), an estimate within 50% of the value is adequate for rating purposes.

Note that large blocks correspond to a low rating (i.e. a stable rock mass with few joints). P9 measures the median D_{50} size of blocks and should not be confused with P2 Qmax which

measures the largest potentially unstable block. R2 increases for larger blocks, reflecting an increasing hazard. However, as R9 decreases, a more massive and stable condition is reflected. R9 is one of the parameters which control the stability of the face, whereas R2 is a measure of the destructive capabilities required for catch fence design.

4.4.3.5 Slake-Durability Index, Sdur (P10)

The slake-durability index, Sdur, measures the resistance of soft rocks such as shales to wetting-drying cycles, atmospheric weathering and erosion (ISRM, 1981; ASTM D-4644-87). Use the descriptive categories given in Figure 14 for rating rocks of moderate to high durability. Laboratory testing is recommended for less durable rocks where disintegration of the rock face caused by wetting and drying (slaking) is likely to lead to an erosion problem. Samples for testing should consist of about 2 kg of shale in one or two large pieces, wrapped in cloth and dipped in wax to preserve their natural water content.

The estimated or measured I_{d2} values can be used to predict rates of erosion using the empirical relationships published by Shakoor and Rogers (1992):

Urate (cm/yr) = 8.66 - 0.1717(Sdur) if Sdur <30%

Urate (cm/yr) = 3.17 - 0.0137(Sdur) if Sdur >30%

Urate (cm/yr) = 2.10 - 0.0119(Sdur) if Sdur >90%

For most Canadian Shield rock masses, the rating for Sdur is 0.

4.4.3.6 Water Table, Wtab (P11)

Groundwater pressure in joints is reflected in the water table, Wtab, which is considered to be the maximum height of emergence from the slope as a percentage of slope height, V12. All heights are measured from EOP level. The water table profile back from the rock face is related to the height of emergence (Hoek, 1970).

The line of emergence is often readily observed from seepages in summer and even more readily from ice formation in winter. The value for rating purposes is the highest expected seasonal level. When the rock mass is highly permeable (i.e. a loose face or one with closely spaced joints), this level will not fluctuate greatly except as a result of winter freezing and ice-damming.

Greater allowance should be made for seasonal fluctuations when the rock mass is tight and observations are made during a dry season. Even in a tight rock mass, the face will generally appear damp below the water table and older exposures may be moss-covered. Take into account the slope of the ground above the crest of the rock cut (i.e. a steep slope will increase the chances of a high water table) and any ponded water, staining, vegetation patterns or fretting of the face caused by freeze-thaw.

4.4.4 FACE GEOMETRY

4.4.4.1 Height (P12)

Transfer the slope height value V12 from the reverse side of the data sheet and circle the

corresponding rating. If measurements of both crest angles and slope distance have been made, then other calculations can be undertaken to evaluate height and an average value for P12 used rather than a single estimate.

4.4.4.2 Crest Angle, Cang (P13)

Transfer the crest angle, Cang, from the reverse side of the data sheet, for the "worst" segment as determined in Section 4.3.7.

4.4.4.3 Clear Zone Width Design Value, Czwd

The design value of clear zone width, Czwd, is defined as the distance from the edge of the travelled portion of the roadway to the face of an unprotected hazard, as recommended in the MTO Roadside Safety Manual and in MTO's Northeastern Region, the High Rock Cut Design Guidelines (NRE 2000-204). Values of Czwd depend on AADT and posted speed limit, as shown in Figure 15. It reflects the current practice to leave a minimum clearance between a rock face and EOP as a precaution against collisions and is compared with actual clear zone width in calculating P14 below.

4.4.4.4 Clear Zone Width, Czw (P14)

Transfer P14 clear zone width, Czw, from the reverse side of the data sheet. The Value V14 is the horizontal distance measured from the edge of the travelled pavement to the rock face, for the narrowest combination of ditch plus shoulder for the designated "worst hazard segment". A clear zone width rating R14 which is determined from the ratio of Czw/Czwd reflects the risk of traffic colliding with the rock face while trying to avoid a rockfall. V14 together with crest angle V13 also provides a check on slope height V12, as described above.

4.4.5 TRAFFIC DATA

Space is also provided on the data sheet to record the following statistics for traffic density, speed etc. used in calculating RHRON values and ratings:

4.4.5.1 Annual Average Daily Traffic (AADT)

In Canada, traffic densities (vehicles/day) vary considerably according to season. Annual Average Daily Traffic (AADT) is used for calculations within RHRON. Summer Average Daily Traffic (SADT) - i.e. for July 1st to August 31st - was previously employed as the basis for scoring, but it creates too conservative an estimate (i.e. greater traffic density) than AADT. Appropriate AADT statistics should be obtained by contracting the applicable MTO Region or can be estimated from older published data obtained from the following Webpage:

http://www.mto.gov.on.ca/english/pubs/trafficvolumes.shtml

4.4.5.2 Posted Speed Limit (Psl)

The posted speed limit, Psl in km/h, is only used for calculating other ratings. Therefore only the value (i.e. not a rating) is recorded. This value is recorded in the field by noting the

posted limit for traffic approaching a hazard. This information is also available through MTO.

4.4.5.3 Sum of Hazard Lengths (ΣLhaz)

The sum of hazard segment lengths, ΣLhaz in metres, is obtained by adding the individual hazard segment lengths from Side 1 of the field data sheet while excluding those that are Stable or have an Adequate ditch. Since ΣLhaz is used in calculating Avr and Dsd, it does not have a rating of its own.

4.4.5.4 Decision Distance (DD)

The decision distance, DD, measures the distance that a vehicle travels while a driver is taking note of an obstacle in the roadway. So it depends on the speed of the vehicle at the time. However, for RHRON purposes, the values published by AASHTO are selected according to posted speed limit (Psl) rather than actual speed.

Note the posted speed limit and determine the corresponding Decision Distance from Figure 9. The Decision Distance is compared with sight distance in calculating V18 Dsd as described below.

4.4.5.5 Ditch Effectiveness, Deff (P15)

Ditch effectiveness, Deff, measures the risk of ditch overspill or the probability of any rock reaching the travelled portion of the highway. The following question could be asked:

> ***Out of one hundred rockfall events of magnitude Qmax, how many would deposit at least some rock on the travelled portion of the pavement?***

In trying to estimate this, several factors need to be considered such as the height and angle of the slope; the ditch width, depth and shape as well as how irregularies in the slope can effect the trajectory of a rock fall or create "launching facilities". Slope irregularies are especially important, since, in certain cases, they can actually cause a falling rock to completely miss a ditch and end up on the road.

4.4.5.6 Overspill, Ovsp (P16)

Overspill amount, Ovsp, is a visual assessment of the percentage of the travelled portion of highway that would be blocked by the Qmax rockfall event. It ranges from zero for a fall that fills the ditch and shoulder only, to 100% (R16 = 9) for overspill onto the farside shoulder or further downslope.

4.4.5.7 Average Vehicle Risk, Avr (P17)

Average vehicle risk, Avr, is a measure of the number of vehicles present in the hazard zone at any given time or the percentage of time that a vehicle is present in the rockfall hazard zone. Avr is calculated from traffic density and sum of hazard lengths, ΣLhaz.

4.4.5.8 Decision Sight Distance, Dsd (P18)

Decision sight distance, Dsd, is the percentage ratio of the sight distance SD at which rock debris first becomes visible to the decision distance DD required for stopping or evasive

action.

Dsd = SD/DD x 100%

Obtain DD from Psl as described in) 4.4.5.4 above. Sight distance SD (m) is a measure of the visibility of rock on the roadway, from a height of 1.5 m as seen from a vehicle approaching the hazard. Estimate the sight distance by measuring the distance to oncoming vehicles from the hazard location with a laser range finder. When the predicted overspill potential (V16) is less than 50%, measure the sight distance only in the nearside lane. When the overspill potential is greater than 50%, take the sight distance as the least value for traffic moving in both directions.

4.4.5.9 Available Paved Width, Apw (P19)

Available paved width, Apw, is the width of pavement available to accommodate motorists trying to avoid a rockfall event. This width is the full paved width for an undivided highway. However, for a divided highway with central barrier or ditch, Apw includes only the accessible (nearside) part of the paved width. Do not include any pavement obstructed by permanent or semi-permanent barriers or obstacles such as road signs and do not include paved shoulders.

4.4.6 FACTOR SCORES, RHRON AND COSTBEN

4.4.6.1 Transfer of Data

Transfer all of the data required for hazard and cost evaluation from Side 1 to Side 2 of the RHRON Field Data Sheet. Complete the upper part of Side 2 using the tables shown in the lower part for the various parameters. Transfer the information into the calculation spreadsheet – this is usually done at the end of the day – and calculate Factor Scores and RHRON values.

4.4.6.2 Calculation of Factor Scores

The spreadsheet automatically calculates the four factor scores as the averages of ratings on which they are based. Circle the appropriate ratings on the 0-9 scale bar and record the factor scores out of 9 to two decimal places.

F1 Magnitude	F1= [R2+R3+R12]/3
F2 Instability:	
Ravelling	F2 = [R1+R9+R11+R4+R5+R6]/6
Sliding	F2 = [R1+R9+R11+R5+R6+R8]/6
Erosion	F2 = [R1+R9+R11+R4+R7+R10]/6
F3 Reach	F3 = [R13+R14+(R15+R16)/2]/3
F4 Consequences	F4 = [R17+R18+R19]/3

Note that the value of F2 used in calculating RHRON is the largest score obtained for any single instability mode. Within the Canadian Shield, Ravelling is almost always the most

critical instability mode. Report F2 values for each mechanism occurring on site to allow comparison.

4.4.6.3 Calculation of RHRON

Determine and record RHRON to two decimal places according to the following formula:

$$\mathbf{RHRON = (F1+F2+F3+F4)/4}$$

4.4.6.4 Calculation of COSTBEN

COSTBEN, the cost-benefit ratio for remedial treatment is obtained from the equation:

$$\mathbf{COSTBEN = Remcost/[RHRON \times (\Sigma Remx/100)]}$$

where Remcost and RHRON are ratings on a scale 0 to 9 and ΣRemx% is the sum of Remx1 through Remx4, i.e. the estimated total percent reduction resulting from the single treatment or treatment combination, with 90% as the standard. The resulting COSTBEN ratio ranges from about 0.4 to 3.5 for normal values of its components (i.e. with RHRON ranging from 5 to 9; Remcost ranging from 3 to 8 and ΣRemx usually at 90%).

RHRON x (ΣRemx/100) is a measure of the benefit to the reduction in RHRON which is expected from the treatment. The optimum benefit is obtained where, RHRON begins at 9 and is reduced by 100% to zero for a hazard reduction also of 9. Whether it is the result of either low remediation costs or high benefits, low values of COSTBEN are considered to be "good".

4.4.6.5 Ranking and Prioritization

Arranging sites in priority sequence is the whole purpose of the hazard rating operation. COSTBEN is recommended as the principal basis for hazard prioritization. However, other considerations include the proximity of candidate sites and similarity of treatments. A sort performed in the RHRON database will prioritize candidate sites, placing the most pressing at the top of the list.

The MS Excel spreadsheet expedites the prioritization process. Sorting is carried out not only using COSTBEN as a sorting criterion but also based on individual factor scores and Remcost.

RHRON ranking presents sites in descending order (i.e. largest RHRON = greatest hazard).

Remcost ranking (i.e. the actual dollar value estimate for remediation) is obtained by sorting V20 and lists sites in ascending order from the least to the most expensive treatment.

COSTBEN identifies and sorts in ascending order. The site with smallest value of the ratio (lowest cost & highest benefit) is ranked #1.

Factor rankings are displayed in descending order according to values for each factor to determine the relative magnitudes, instabilities, reaches and consequences.

At each stage of sorting, an additional column is added to the spreadsheet so that on subsequent sorting, a record of the previous rankings is retained. Finally the data table is rearranged to present sites in ascending order based on Highway Number and Site Number.

5.0 Supplementary Notes

5.1 AIDS TO SITE DATA ACQUISITION

5.1.1 DIGITAL IMAGERY

5.1.1.1 Purpose

Digital images of the rock face are required to illustrate the typical character of the rock mass, condition of the face, and the mode of instability. Reliable results call for some basic precautions in image taking and in selecting suitable viewpoints. Digital images provide increased options for communication and information processing far more efficiently than still photographs. Depending on the format required for reproducing the image, certain minimum criteria need to be met.

Digital images taken with a digital still camera should be a relatively high resolution. Images with greater resolution or better colour depth require larger files and subsequently increased storage space. File compression formats, e.g. JPG, can reduce file sizes by almost a 30:1 ratio, with little noticeable loss of image quality.

5.1.1.2 What to record

Two to five good shots of typical conditions per site should be sufficient. However, storage is inexpensive compared with the value of a good digital record and the cost of getting to and from the site. So it is generally good policy to take two to three times the number of shots needed, then select the best and discard the rest. For follow-up detailed design work, more extensive images will be needed, possibly in the form of photo-mosaics. A record is required of the following:

1) Typical quality of the rock mass including joint spacing (block sizes), orientations, apertures, water seepages and ice build up;
2) Typical condition of the face and ditch, extent and type of vegetative cover, slope height and inclination, face irregularity and looseness;
3) Typical examples of instability including mechanisms and geometry of previous or potential falls and slides, amounts and sizes of talus and rockfall debris, damage caused by previous falls, settlements, tension cracks etc. diagnostic of ongoing movements; and
4) Typical locations and types of treatment, areas to be scaled or shotcreted, locations of rockbolts, drain holes, underpinning etc.

5.1.1.3 Where to record images

For long rock cuts it is useful to take one oblique image from the farside shoulder at the

beginning of the hazard to give a complete overview of the site. At a minimum, images should be taken at the "worst hazard segment", with at least one oblique shot showing an extended length of face, plus shots taken to highlight specific features. With digital cameras, it is usually best to consistently shoot in "landscape" mode for presentation purposes. The number of shots and time taken are recorded on Side 1 of the Field Data Sheet to assist in later cataloguing of the digital images.

5.1.1.4 Timing of Evaluations

Winter should be avoided for conducting rock hazard evaluations. In addition to the usual safety issues involved with winter work on roadways, snow obscures ditches as well as significant (i.e. especially the lower) portions of rock cuts.

Spring is the best time of the year for evaluations after the snow is gone and just before the leaves begin to come out. Fall is also a good time, after the leaves have fallen and been removed from ditches (i.e. in areas where that's necessary).

Bright days give best results but try to avoid excessive shadows on very sunny days or taking pictures late in the afternoon. Stop work in early evening while the light is still adequate. Images of east-facing cuts are best taken in the morning, while west-facing ones are best taken in the afternoon.

5.1.1.5 Method

Fill the field of view with the rock face, showing just enough sky and road to define the crest and ditch conditions.

Include at least one scaling object of known length in the image, such as a 1.5 m long wooden scale bar sawn from 12 x 50 mm stock and painted black-orange-black in alternate 0.5 m segments or a 7.5 m long ranging pole. Position the scale bar vertically at the centre of the selected view.

If the rock face is oblique to the camera, place identical scaling objects at the nearest and furthest points so that they can be used for "tilt correction". For shots oblique to a vertical face, this means two vertical scale bars resting against the face at two locations along the nearside ditch. For shots of an inclined face (e.g. talus slope), horizontal scale bars resting at different heights on the rock face are required.

If possible, identify images by a site number in the field of view and using the date marker provided in the camera. Take care to select the appropriate background and labelling colours for photo identification. A dark green background or "blackboard" is best with contrasting lettering. Downloading of site photographs to site-specific folders prior to leaving the site also helps to keep them organized when having to rate numerous sites.

Maintain cameras in good working condition. Lenses can be cleaned using compressed air to avoid scratching.

5.1.2 DICTATED SITE NOTES

Supplementary field notes provide a very useful addition to the contract report; particularly when accompanied by photographs and/or sketches.

To obtain the maximum amount of information in the limited time available, these field notes should be dictated during or immediately after completion of hazard rating at a site (i.e. for example while travelling between sites). To obtain a concise and consistent sequence of reporting, it is suggested that the dictated notes follow an eight-point checklist:

1) Rockfall history and quantities;
2) Type and degree of instability;
3) Reach, and adequacy of existing catch facilities;
4) Consequences, likelihood of a rockfall causing an accident, and any non-vehicular risks;
5) Recommended treatment and alternatives;
6) Cost (high, medium or low) and factors affecting cost;
7) Likely effectiveness and durability of treatments; and
8) Need (if any) for supplementary investigations.

5.2 RHRON FACTORS

The following is a brief account of the reasoning behind the selected composition and range of parameters that comprise the four RHRON Factors.

5.2.1 MAGNITUDE FACTOR, F1

$$F1 = (R2 + R3 + R12)/3$$

F1 represents the maximum and total volume as well as the height of the potential fall. It includes the mass, velocity, energy, cleanup quantity and thereby the cost of potential falls. F1 = 9 corresponds to a site with 10 cubic metres per event, 100 cubic metres of total potential fall and a 30 m slope height. These arbitrarily selected limits provide a reasonable level of sensitivity to the more frequent small to medium-size rockfall events. The range of potential rockfall and slide volumes is actually much larger than this, extending to millions of cubic metres. These mega-slides are fortunately rare events and to accommodate them in the RHRON score would compress the scale and make the F1 and RHRON scores insensitive to the more common variations.

5.2.2 INSTABILITY FACTOR, F2

F2 represents the probability and/or frequency of Qmax, the largest potential fall or slide. It ranges from 0 (likely stable) to 9 (collapse is imminent).

Different mechanisms are controlled by quite different processes and parameter

combinations. Hence, the Instability Factor is evaluated differently for each of three instability categories:

F2 = [R1+R9+R11+R4+R5+R6]/6 Ravelling mode

F2 = [R1+R9+R11+R5+R6+R8]/6 Sliding mode

F2 = [R1+R9+R11+R4+R7+R10]/6 Erosion mode

Separate consideration of mechanisms makes a maximum of about a 10% difference to the final RHRON score and is an added complication that was considered at some length before including it as a feature of the system. However, it is unrealistic to evaluate sliding on the same basis as ravelling, for example and the complexity of the rating system is more of a psychological problem than a real one since no further observations are required and the calculations are handled by computer.

The three categories have the following evaluation criteria in common:

a) History and on-site evidence of previous falls (i.e. larger falls are nearly always preceded by a history of smaller events);

b) Block size (intensity of jointing) is particularly critical for ravelling but also affects all mechanisms; and

c) Water table determines the effective stress (and hence the shear strength of a sliding surface) and also the potential for near-surface frost action and ice-jacking.

In addition to these common parameters, the F2 score takes into account three other parameters of particular relevance to the instability mode. The assessment of ravelling/toppling instability takes into account face irregularity, joint orientation/persistence and aperture (i.e. face looseness). Open cracks may well be the most important indicators of the extent to which loosening has progressed and the imminence of collapse. Sliding instability depends largely on the shear strength of the surfaces of sliding and erosion/undercutting assessments take into account the intact strength and slake-durability of the rock which are important considerations for soft rocks, in particular.

5.2.3 REACH FACTOR, F3

F3 = [R13 + R14 + (R15 + R16)/2]/3

This is a measure of how much rock would spill onto the highway and will depend on the effectiveness of the ditch and any other barriers in relation to the volume, velocity and trajectory of falling rock.

Crest Angle R13 provides a comparison between actual and ideal rock catch widths. It has been extensively investigated and data is available which relates percent overspill to crest angle, ditch width and type. It can also be measured objectively with little or no judgement, which is why it has been selected as a key criterion for preliminary screening. In contrast, estimates of rock stability and probability of failure are difficult and unreliable even for an "expert".

Nevertheless, experience and judgement are often the most direct and sometimes the only

way to assess risks and provide an important ingredient at the detailed assessment stage, in particular. R14, the clear zone width, is another important parameter when considering Reach. It adds to the understanding of the geometry of the site and especially looks at the size of the ditch needed to evaluate the other components. The Reach Factor is rounded off by two entirely subjective parameters, R15, ditch effectiveness (i.e. the probability of any rock reaching the pavement) and R16, the overspill potential (i.e. the percentage of the highway likely to become blocked).

5.2.4 CONSEQUENCES FACTOR, F4

F4 = [R17 + R18 + R19]/3

This is an estimate of the damage likely to be caused by that part of the Qmax rock that would overspill onto the pavement. The risk of an accident depends on visibility of the rock, traffic density and speed in addition to time and space required to swerve or stop. F4 ranges from zero (i.e. a slight hazard for an inattentive driver) to 9 (i.e. the accident is unavoidable).

Hazards of a non-vehicular type should not be overlooked, although they are omitted from RHRON. These include potential damage to railways, power lines, houses, factories etc. resulting from rockfalls originating at or above highway level and arguably triggered by highway construction. Such hazards, although important when they do occur, are relatively uncommon. Non-vehicular risks were included in an earlier version of RHRON but were found to dilute the score with a large number of zero ratings. These risks should be separately reported, since they will often affect the selection of treatment priorities.

5.3 INSTABILITY MECHANISMS, DIAGNOSIS AND TREATMENT

The following are definitions of some of the more common types (i.e. "modes" or "mechanisms") of slope instability with some characteristic features and typical treatments.

5.3.1 MECHANISMS AND TREATMENTS

5.3.1.1 Ravelling

Ravelling includes the fretting away of small fragments of rock which have been loosened by weathering as well as random block falls that occur when key blocks are removed. It is most prevalent where the block size is small to medium (i.e. up to 30 cm) and where there is well developed jointing. Joint sets, per se, may not be present but the rock mass would commonly be described as blocky. A talus slope often develops below the ravelling face, which may take the form of high bluffs above an upslope which in turn overlies the blasted rock cut. Typical treatments include scaling and ditch clean out and re-shaping of catch facilities.

5.3.1.2 Overhang collapse

Overhang collapse is caused by the undercutting of a section of the rock face, as a result of

differential weathering, uneven blasting, or river erosion acting at the toe of the slope. Critical factors determining the degree of instability are the rate of undercutting (i.e. which may be determined by slake-durability index when caused by atmospheric weathering) as well as the joint spacing and persistence within the overhanging, more competent, stratum. Alternatives for remediation include underpinning of the overhanging section using shotcrete, concrete or dental masonry or the removal of the overhang by scaling or trim blasting.

5.3.1.3 Ice Jacking

Ice Jacking is caused by the freezing of water in joints located close to the exposed rock faces. Depending on the size of block or slab rendered unstable, ice jacking may result in either ravelling or toppling. Critical factors in determining the degree of instability are the frequency of cycles of freeze-thaw experienced locally, the depth of frost penetration, the availability of water as expressed by P11 (Water Table) and the closeness of jointing (P9 Block Size). Typical treatments include sealing of slope crest cracks with asphalt, diversion of water away from the crest, drainage of the face when drilling of drain holes is feasible, scaling of loose rock or provision of catch facilities.

5.3.1.4 Block Bouncing

Single block bouncing and rolling may result from isolated loose blocks which are present as rounded boulders in soil overburden on the upslope or isolated angular blocks in the upper part of the blasted face. These blocks are loosened by weathering or seismic accelerations and bounce and roll away to the base of the slope. Their energy, height of bounce and reach depend on their size and initial height as well as on the angle and rebound capabilities of the slope face.

Face irregularity is another important consideration, particularly the presence or absence of projection features (ledges) that may project the falling block clear of any catch fence or ditch. Remedial treatments include scaling of loose rock, trimming and removal of launching features or the provision of appropriate catch facilities. Large unstable blocks may require blasting or may be secured by cable lashing.

5.3.1.5 Sliding

Sliding modes of failure include translational failure of hard rock blocks bounded by joints, rotational failure of soils or closely jointed rock sliding along a spoon-shaped surface. Deep-seated hard rock slides generally take the form of 3-D pyramid wedge sliding where the unstable block rests on two sliding surfaces. Very large masses or thin slabs tend to fail by 2-D sliding along a single sliding surface.

Typical treatments include drainage of the surface of potential sliding to relieve water pressure, buttressing of the toe of the slide (i.e. very often using material cut from the crest) or installation of long high tensile anchors (i.e. which generally are not very cost-effective except for thin slabs where large numbers of less expensive rockbolts can be employed). Drainage is often useful provided that that the drain holes can be kept open and that the water used in drilling the drain holes themselves will not destabilize the slope. This can be problematic in Canadian winter conditions.

5.3.1.6 Toppling

Toppling occurs by rotation of a thin slab bounded by near vertical joints. Generally the slab is parallel to the rock face. If several closely-spaced joint sets are present, toppling may be combined with ravelling and/or ice jacking. Typical treatments include drainage and/or rock bolting, if the face can be safely drilled, or scaling/trim blasting if not.

5.3.1.7 Erosion

Erosion is generally confined to closely-jointed or very soft rock. However, more massive and stronger rocks can be eroded where their slopes are undercut by rivers or impacted by marine waves, or by hydroelectric turbine tailraces in spillway channels, where the velocity of water is very high. Preventative measures and treatments for erosion include toe buttressing with gabions and re-vegetation once the undercutting has been arrested. Protection against high velocity water can sometimes also be provided by rock bolt reinforcement or by the construction of concrete liners or gabion walls.

5.3.2 CRITERIA FOR SELECTING TREATMENTS

There is little doubt that ravelling, block falls and ice jacking are the dominant modes of failure for rock masses in the Canadian Shield (i.e. in MTO's Northeastern and Northwestern Regions) where the vast majority of the rock cuts are located. The principal decision to be made is whether the rockfall hazard should be controlled by Removal, Reinforcement, Catchment or Protection. Most MTO projects end up with the majority of the effort being placed in removal of the hazard. Other considerations include:

- If a treatments is unsuitable for the conditions (e.g. difficult access, hazardous to install, environmentally unacceptable or unlikely to succeed) - Estimate the types and quantities of remediation required from those that remain;
- The cost-effectiveness of alternatives including the likely success and durability of the treatment(s) as well as any ongoing maintenance requirements; and
- Any risks that are involved in the treatment such as danger to contractors' personnel or to the public and the anticipated duration and requirements for partial or full highway closure.

Select the treatment that best maintains the natural appearance of the rock face whenever possible. Less obtrusive means of treatment tend to be more expensive than unsightly large areas of concrete, shotcrete, bolts, straps and other artificial materials. However, the additional expense is often worthwhile. For example, masonry can provide an attractive alternative to concrete for underpinning overhangs. Blocks of local rock bonded by cement mortar blend with the appearance of the natural rock outcrop. Alternatively, repair concrete can be made less conspicuous by exposing large size aggregate by washing, brushing or bush-hammering treatments. Pre-cast panels with a variety of textures and colours are also available for surface application.

Provided that the rock is hard and durable, fully resin-bonded rockbolts can be made to "disappear" by omitting faceplates. Provided that the bonding is complete, the outermost rock block substitutes for a faceplate. Exposed steel components including bolt ends,

faceplates and straps, where used, should be painted to prevent rusting and unsightly staining of the face. However, aesthetic considerations rarely appear to be appropriate for the majority of highway engineering projects.

5.3.3 BENCHES, FENCES AND DITCHES

Fences on the downslope side adjacent to the highway interfere with snow removal, which is a significant consideration in northern climates. Catch fences are best located on the upslope side of the ditch, where room is available. If possible, leave a shoulder between the catch wall or fence and the rock face, that is wide enough to permit front end loaders or other mechanical maintenance equipment to operate behind the barrier. Jersey barriers (i.e. removable concrete precast sections) can contain small fragments yet are readily removed and reconstructed to facilitate cleanout of snow or rock debris. The maintenance issues, however, have often precluded the use of these techniques.

Rockfall catchment fences supported by posts and guy wires with friction brakes may be used to catch fast-moving boulders. Impact velocities can reach 20 km/h and height of bounce can be 5 to 8 metres in extreme cases. The design of these fences usually involves rockfall simulation using a computer program to estimate the energy requirements. Fences have been used with energy capacities of up to 2,000 kJ and testing has been carried out for fences with even higher energy capacity.

Overburden soil and, when present in sufficiently small sizes, the rockfall debris itself, can provide an inexpensive source of material for bench or berm construction and a very effective catch capability. Benches should be ramped up from the highway to either side of the hazard, to give access for periodic bulldozer cleanup and re-grading.

Field trials such as those by the Oregon Department of Transportation (Pierson et al, 1994) define the reach of rockfall debris in relation to the height of face and dimensions of ditch. This information, together with research on the natural angles of talus slopes, provides a basis for selecting a clear zone width that is appropriate for a given slope height.

Relatively flat slopes with critical crest angles that are as low as 27° (see Figure 16) are required for talus ramps on hillsides (i.e. reach = 1.9 x height).

A crest angle limit of about 53° will ensure 100% ditch retention for a 1.25H:1V rock cut (i.e. with Czw = 0.75 x height). However, often there is no room for a ditch this wide. The crest angle can be increased to 62° (Czw = 0.5 x height) if a 20% overspill (i.e. 80% retention) can be tolerated or to about 69° (i.e. with Czw = 0.4 x height) by deepening the ditch into a "Ritchie" cross-section (Ritchie, 1963 and Figure 17). When the width and depth of ditch required by the height of slope cannot be accommodated, other measures such as draped mesh, bench blasting or rock catch fences are needed.

The required clear zone width depends not only on slope height H but also on the ditch shape and depth. Based on Oregon experimental data, for a triangular cross-section ditch of height H and depth h, the relationship is approximately as follows:

Czw = 0.5 H - 4.0 h for 95% retention

Czw = 0.9 H - 4.47 h for 100% retention.

5.3.4 SCALING OR STABILIZATION?

At many sites a basic choice exists between holding the rock up, or bringing it down. Much effort can be expended in vain securing loose blocks to each other with the result that the face collapses in large sections instead of small fragments. Along the Niagara Escarpment in Hamilton, Ontario, for example, scaling of the loosened dolostone face has been adopted as routine treatment. In earlier experiments, shotcrete was applied locally but the treatment was expensive and unattractive. The following are some advantages of scaling:

- Durability - Looseness of the face is often caused by a combination of initial blast fracturing and subsequent frost action. Once the blast-damaged material has been removed, scaling treatment can last for at least several decades. Shotcrete is susceptible to cracking and can deteriorate, particularly if it is poorly drained. Scaling is more apt to provide a permanent solution.

- Appearance - The natural appearance of the rock face is preserved by scaling treatments. However, it is obscured and marred by reinforcement and retention alternatives.

- Speed - With well-executed mechanical scaling, the unstable sections are often rapidly removed leaving a smooth, stable face requiring no further remediation. Highway closures can be minimized.

- Creation of setbacks - When scaling brings down large quantities of loose rock, it also creates much-needed ditch space where, at the outset, setbacks from the edge of pavement were minimal or non-existent.

- Test for stability - Scaling or "sounding" provides a test for stability of the rock face as well as a treatment. Frequently, rock that appears securely attached comes down with just a light touch of a scaling bar. In other cases, areas that appear loose turn out to be securely attached.

The following are some considerations when selecting and drawing up contracts for scaling and trimming treatments:

- Trimming is used on overhangs when the rock cannot readily be removed by scaling. Explosives or hydraulic jacks can be employed in upslope tension cracks, if drilling of blast holes is hazardous. For safety reasons, trimming and scaling generally proceeds from top-to-bottom. However, the face can also be trimmed and scaled from end to end, with workers and equipment operating within a previously stabilized area and extending it laterally.

- In weak or closely jointed rocks, hoe-ram scaling is so efficient that an experienced operator can keep trimming almost indefinitely. This work requires close supervision to prevent unwanted removal of rock. Backhoe excavator machine scaling would be preferred under these conditions. Manual scaling is used mainly at locations that are inaccessible to the machine. The height of mechanical scaling is limited by the reach of the machine but it can be extended several metres by working off ramps of rock debris. There have been some restrictions placed on manual scaling with ropes and belts in Ontario. This

method must be carefully considered and planned, in order to be effective.

- The amount of scaling is difficult to predict beforehand and to measure on completion. Prediction of quantities is based on estimates of in-situ volumes converted to bulked volumes by the application of an appropriate bulking factor. Often the number of truckloads to be hauled from the site is underestimated because of an optimistic impression of the integrity of the rock face or of the degree of control that can be exercised during scaling work.

  Decisions on quantities to be scaled should be made at the time of the work. This requires some change of emphasis in the usual forms of contract.

  In mechanical scaling, the skill and experience of the operator and the capabilities of equipment are important considerations when awarding the contract. Manual scaling also requires a high level of skill and experience for personnel working on ropes high on the rock face.

  Because of the noise generated by the machine, continuous radio contact between the contractor's foreman and the machine operator is essential.

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Appendix 1

Terms and Abbreviations

AADT	Annual Average Daily Traffic
Apw	Available Paved Width - the width of pavement available to accommodate both fallen rock and motorists trying to avoid the rock pile. This width includes, for an undivided highway, the full paved width of roadway. For a divided highway with central barrier or ditch, Apw includes only the accessible (nearside) part of the paved width. Paved shoulders are not included.
ASTM	American Society for Testing and Materials
Avr	Average Vehicle Risk - a measure of the number of vehicles present in the hazard zone at any given time, or when a fractional quantity, the percentage of time that a vehicle is present in the rockfall hazard zone.
Basic RHRON	A simplified version of RHRON used in a preliminary screening of sites.
Base Friction Angle ϕb	The angle whose tangent is the ratio of the shear strength of a joint after all roughness asperities have been ground smooth by shearing to the “normal” stress component perpendicular to the plane of the joint.
Block fall	A rockfall consisting of a single block of rock.
Block size ("Block")	The average linear dimension (cm units) of a typical "block" in the face.
Block rolling/ bouncing	A mode of rockfall instability in which isolated loose angular blocks in the blasted face or rounded boulders in soil overburden on the upslope become detached and gather momentum as they fall.
Breccia	Broken angular rock fragments, gravel size or larger, created by shearing (see also “gouge”).
Cang	Crest angle measured from the pavement level to the highest potentially unstable rock - the angle whose tangent is the ratio of slope height to width of clear zone Czw for a vertical rock face.
Class A, B and C	(see Hazard Class)

Continge	A contingency allowance for all non-unit price items equal to the ratio of anticipated total contract cost divided by Costnet.
COSTBEN	Cost-benefit ratio for remedial treatment. COSTBEN = Remcost/[RHRON x (ΣRemx%/100)].
Creep	A mode of slope failure characterized by slow sliding movements accumulating over months or years, generally confined to soils, shales and closely jointed or sheared rock types.
Costnet	The net total estimate for unit price items.
Czw	Clear zone width - the horizontal distance from EOP to the rock face; the narrowest combination of ditch plus shoulder width within the designated "worst hazard segment".
Czwd	Minimum design value of clear zone (ditch plus shoulder) width recommended in the MTO Roadside Safety Manual (i.e. values of Czwd depend on AADT and speed limit).
DD	Decision distance - the distance a vehicle travels while a driver is taking note of an obstacle in the roadway. It depends on the speed of the vehicle at the time.
Deff	Ditch effectiveness - the probability of any rock reaching the travelled portion of the highway. Out of one hundred rockfall events of magnitude Qmax, the number that would deposit at least some rock on the pavement.
Detailed Rating	The RHRON score obtained by applying the full RHRON procedure to the hazard site (as opposed to the Basic RHRON used in preliminary screening of sites).
Dipmag	Dip magnitude of a joint, measured 0° to 90° down from horizontal in the steepest direction of dip.
Discontinuities	All types of weakness plane in the rock mass, including faults, shears, bedding planes and surfaces of schistosity and cleavage - in addition to "joints" as defined by the geologist.
Downslope	The part of the natural hillside that extends below the highway.
Dsd	Decision Sight Distance - the percentage ratio of the sight distance SD at which rock debris first becomes visible, to the decision distance DD required for stopping or evasive action.
EOP	Edge of Pavement - the junction between the travelled portion of the asphalt or concrete pavement and the paved or unpaved shoulder which is usually identified as a white line.

Factors F1-F4	Components of RHRON: F1 Magnitude; F2 Instability; F3 Reach and F4 Consequences. Factor scores are obtained as the averages of ratings on which they are based.
Firr	Face irregularity index based on a combination of % half-barrels visible, depth of overhangs and undercuts and thickness of shotcrete required to smooth the face.
Gouge	Crushed rock fragments, usually ground to a clay consistency, created by shearing.
GPS	Global Positioning System using satellites for locating a position on earth.
Hazard Class	Preliminary classification of potential sites into Class A which require a detailed rating, Class B which require an on-foot inspection and Class C which can be designated safe without leaving the inspector's vehicle.
Hazard segments	Lengths of the rock face along which the type of instability and degree of hazard are more or less constant.
Hbr	Half-barrels index - a measure of blast overbreak and face smoothness, equal to the ratio of total length of visible blast drill hole remnants expressed as a percentage of length drilled.
Half-barrels	(see Hbr).
Height	Upper limit of potential instability above EOP.
Ice Jacking	A mode of slope failure caused by the freezing of water in joints located close to the exposed rock faces.
Impersistent	Discontinuous or lacking in persistence (see "persistence")
Interlocking joint	A joint with a filling thickness less than the roughness amplitude that has not been pre-sheared.
ISRM	International Society for Rock Mechanics.
JCS	Joint Compressive Strength.
Joint	A natural fracture, crack, fissure or plane of weakness in the rock mass. Often loosely used to cover all types of weakness planes and is a simpler alternative to "discontinuity".
Jop	Joint orientation/persistence rating - defined in terms of the persistence (continuity) and azimuth (direction) of the "worst" joint or joint set.
JRC	Joint Roughness Coefficient.

LF See Launching features.

Launching features Projections on the rock face that prevent free-fall of debris into the ditch and divert fragments onto the highway.

Lhaz (see ΣLhaz).

LHRS Linear Highway Reference System - a method for locating sites on highways using offsets measured from south to north or from east to west from landmarks such as highway intersections. This method of locating is commonly found to be highly inaccurate and difficult to duplicate.

Loose Face looseness measured in terms of the number of open joints visible in the face, their typical apertures and an assessment of how easily the rock can be scaled by machine or by hand.

MTO Ministry of Transportation, Ontario

Mylonite Crushed rock created by shearing, e.g. "clay mylonite" created by shearing of shales.

Ohg Overhang.

Orientation The azimuth (direction) of a joint expressed as its dip magnitude (0°-90° down from horizontal) and dip direction (0°-360° clockwise from North).

Overbreak Unwanted removal of rock by blasting including cavities in the rock face caused by excessive use of explosives.

Overhang collapse A mode of slope failure caused by the undercutting of a section of rock face as a result of differential weathering, uneven blasting or erosion by a river acting at the toe of the slope.

Ovsp Overspill index - the percentage of the travelled portion of highway that would be blocked by the Qmax rockfall event.

Persistence Continuity of a joint- the ratio of an un-bonded area to total area in the plane of the joint.

Phip The peak angle of shearing resistance - a measure of the shear strength of rock joints.

Photoanalysis Analysis of digitized images of the rock face (or talus or blasted rock fragments) to obtain information on the geometry of jointing and, particularly, the size distribution.

Preliminary screening Compilation of a highway rockfall hazards log showing the locations of rock outcrops and faces and categorizing the

	sites into Class A, B or C according to the level of hazard.
Psl	Posted speed limit (km/h) for traffic approaching the hazard.
Qmax	The in-place volume of the largest and most hazardous expected single rockfall or slide "event".
Qtot (ΣQtot)	The in-place volume that would be removed, if the face were to be carefully scaled, or in the case of a slide, the total amount of rock that you would expect to come down in a 20 year period as a result of natural weathering, earthquakes etc.
Ranking	Prioritization of hazard sites obtained by sorting the RHRON database so that the most urgent sites (or those of least cost and greatest benefit) appear at the top of the list.
Rating	A number assigned to a parameter, on a scale 0 ("good") to 9 ("bad"), to reflect its contribution to the rockfall hazard.
Ravelling	The fretting away of small fragments of rock loosened by weathering etc.
Remcost	Estimated gross remediation cost (Costnet x Continge).
Remediation	Removal of a hazardous rock condition.
Remx1 - Remx4	The "Remediation Effectiveness Indices" which measure the anticipated success of each of the four categories of treatment. A Remx of 100% in any one category indicates that the treatment in this category alone would be sufficient to entirely and permanently remove the hazard.
RHRON	The Ontario Rockfall Hazards Rating, obtained as the average of four factors (F1+F2+F3+F4)/4, ranging from 0.00 to 9.00. RHRON refers either to the rating score or the rating system.
RHRS	Rockfall Hazards Rating system (Oregon Department of Transportation). RHRS refers either to the rating score or the rating system.
Scanline	A line along a rock face where the spacing and other jointing properties are measured.
SD	Sight distance (m) - a measure of the visibility of rock on the roadway, from a height of 1.5 m, as seen from a vehicle approaching the hazard.
Sdur	The slake-durability index (Id2%) - a measure of the resistance of soft rocks such as shales to wetting-drying cycles, atmospheric weathering and erosion which is determined as the percentage of material remaining after

	two standardized cycles of wetting and drying.
Segment	(see Hazard Segment)
Shotcrete	Concrete applied to the rock face by spraying, for purposes of stabilization
Shot (cm)	The average thickness of shotcrete that would be needed to produce a locally smooth and stable face.
Slake-durability index	(See Sdur)
Slickensides	Shiny, striated (scratched or grooved) surfaces created by shearing along joints or faults
Sliding	Sliding modes of failure including translational failure of hard rock blocks bounded by joints, rotational failure of soils or closely jointed rock sliding along a spoon-shaped surface cutting through the intact material. Includes 3-D pyramid wedge sliding where the unstable block rests on two sliding surfaces and 2-D planar sliding on a single basal joint.
Strength reduction factor "F"	The ratio of joint surface compressive strength (JCS) to strength of the intact material (UCS)
Strike	Normally defined as the angle between north and a horizontal line in the plane of a joint. For hazard rating purposes strike is defined relative to the strike of the crest (i.e. zero for joints striking parallel to the crest).
Toppling	A mode of slope failure characterized by rotation of thin slabs of rock bounded by near vertical joints.
UCS	Uniaxial Compressive Strength of "intact" rock material such as can be determined by applying compression to a cylindrical specimen of rock until it fractures.
Uct	Undercut such as created by erosion, ravelling or over-blasting.
Unbonded	Lacking adhesion
Unweathered	"Fresh" rock unweakened by chemical, physical or biological weathering.
Upslope	That part of the natural rock slope above the highway not including the blasted rock face.
Veh	Vehicles
Wtab	Water table index - maximum height of emergence of groundwater from the slope as a percentage of slope height
ΣLhaz	Total hazard length - obtained by adding individual hazard

segment lengths together.

ΣRemx The sum of individual Remx (remediation effectiveness) percentages for each type of treatment, reflecting their individual contributions to the overall remediation plan. ΣRemx is 100% where the treatment is deemed to be so effective as to preclude long-term maintenance costs and repair treatments at least for the next 20 years.

ϕb (see Base Friction Angle)

APPENDIX 2

Figures

List of Figures

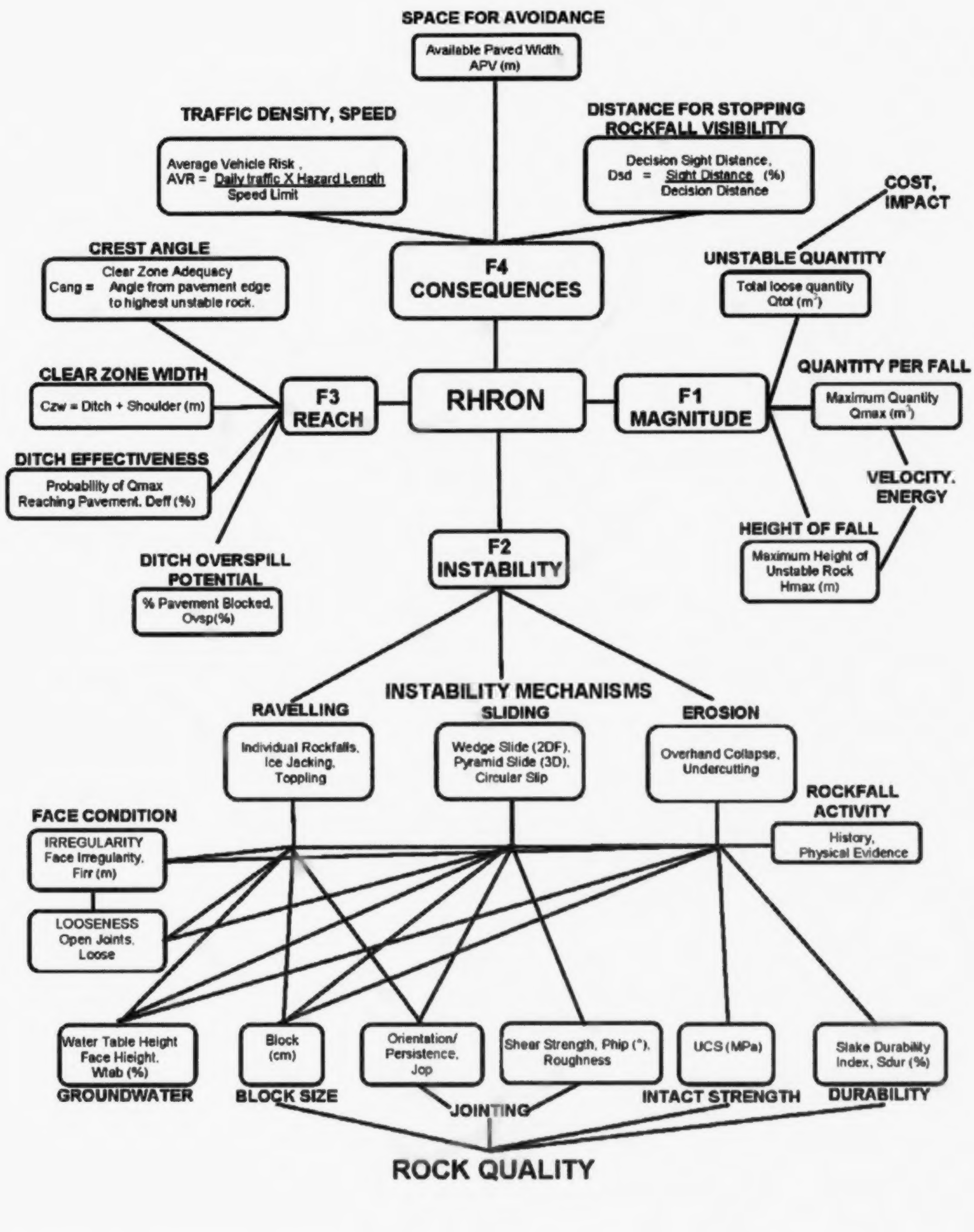

Figure 1 - Composition of RHRON

MEASURING Etc.:

- Binoculars
- Compass, geological, for measuring slope crest & joint strikes and dips. e.g. Brunton, Silva
- Clinometer for accurate measurement of angles (20° to 80° up from horizontal.)
- Measuring wheel for measuring lengths and widths of pavement, which reads to 0.1 m
- Tape measures, 60 metre and 5 metre
- Ranging Pole, 7.5 metres fully extended
- Laser rangefinder with reliable sensitivity from about 4 metres to 500 metres for distance measurements.
- Straightedges, 10 cm and 1 m, and ruler or depth gauge for measuring roughness and waviness amplitudes.

SITE LOCATION AND MARKING-OUT:

- Maps, pre-marked to show site locations, LHRS start points and routes.
- Paint, yellow/white spray cans for marking segment intervals on rock face.
- Spray paint in rock colour for overpainting incorrect markings.
- Global positioning instrument

SAFETY (PPE):

- Workboots
- Brightly coloured/ fluorescent vests and hardhats.
- Gloves when painting
- Sunscreen and bug dope
- Warning signs & flags
- Flashing lights for vehicle.

PERSONAL:

- Clothing, weatherproof
- Packed lunches
- Overnight equipment
- First Aid kit
- Safety Flares

PHOTOGRAPHY:

- Digital Camera, spare batteries, battery charger
- Scale bar for photography, such as 50 x 25 mm wooden bar cut to length 1.5 m, painted black-fluorescent orange-black in three 0.5 m sections. At least two such bars for use when photographing an inclined face. A 7.5 m long ranging pole also useful
- Number board for site identification in photos, fluorescent orange numbers on background similar to colour of rock, weatherproof.

DATA RECORDING:

- Data sheets: RHRON preliminary and/or detailed, with spares.
- Clipboard and weatherproof containers for data sheets, pencils or ballpoint waterproof pens
- Dictating machine and tapes

DATA PROCESSING:

- Laptop computerwith DC power adapter,
- RHRON Software (Excel spreadsheet)

SAMPLING:

- Sample bag(s) if rock samples are to be taken
- Waxing equipment if shale samples to be taken for durability testing.
- Markers, waterproof for numbering rock samples

Figure 2 - Field Equipment Checklist

RHRON Highway Rockfall Hazards Log

Page ____ of ____

				LHRS		Alternative GPS Location Details			Mechanism		Factor					Hazard Class	
Hwy #	Site #	Direction of Lane(s)	Side NSEW	Basepoint	Offset	Zone N/A	Northing Latitude	Easting Longitude	SROIBWPT	Cang	1	2	3	4	Basic RHRON	A:B:C	Notes and Remarks

Figure 3 - RHRON Highway Rockfall Hazards Log

Ministry of Transportation

Ontario Rockfall Hazard Rating System (RHRON) - PRELIMINARY SCREENING DATA SHEET

Highway #:		AADT:	
Site #:		GPS Unit:	
Direction of Lanes:		GPS Zone:	(NAD 83)
NSEW:		GPS Coordinates:	N
LHRS Base point:			E
LHRS Offset Distance:		Waypoint #:	
ROCKFALL WARNING SIGNS:	Yes / No	Digital Image Time:	

Stable		Check (✓) all that apply	Measured crest angle (B) =	
Ravelling			Measured crest angle (A) =	
Overhang			Slope Distance S_A (if measured) =	
Ice-Jacking			Czw =	
Block (single)			Roadway width (between white lines) X =	
2d Wedge			H.I. =	
Pyramid			Cang =	
Toppling			Basic RHRON required (Cang>27)	Yes / No

COMMENTS:

UTILITIES:

RHRON FACTORS:

F1=

F2=

F3=

F4= F4(Avg)=

RHRON = (F1+F2+F3+F4) / 4 =

Rated by:

HAZARD CLASS (A, B or C): Date:

	F1 - MAGNITUDE	F2 - INSTABILITY	F3 - REACH	F4 - CONSEQUENCES	
RATING	**Qtot (m^3)**	**Frequency of falls**	**Crest Angle - Cang (degrees)**	**Traffic Density (AADT)**	**Visibility of rock on highway**
0	1	> 100 yr (slight chance of a fall)	20	0-750	> 250 m
1	2	50 yr	27	750-1500	233
2	3	10 yr	33	1500-3000	217
3	5	5 yr	40	3000-6000	200
4	8	Annually	47	6000-11000	183
5	13	6 Monthly	53	11000-20000	167
6	21	Monthly	60	20000-35000	150
7	36	Bi Weekly	67	35000-65000	133
8	60	Weekly	73	65000-110000	117
9	> 100	Daily - Highly unstable, collapse imminent	80 (high face, narrow shoulder)	> 110,000	< 100 m (very limited visibility)

Figure 4 – Preliminary Screening Data Sheet

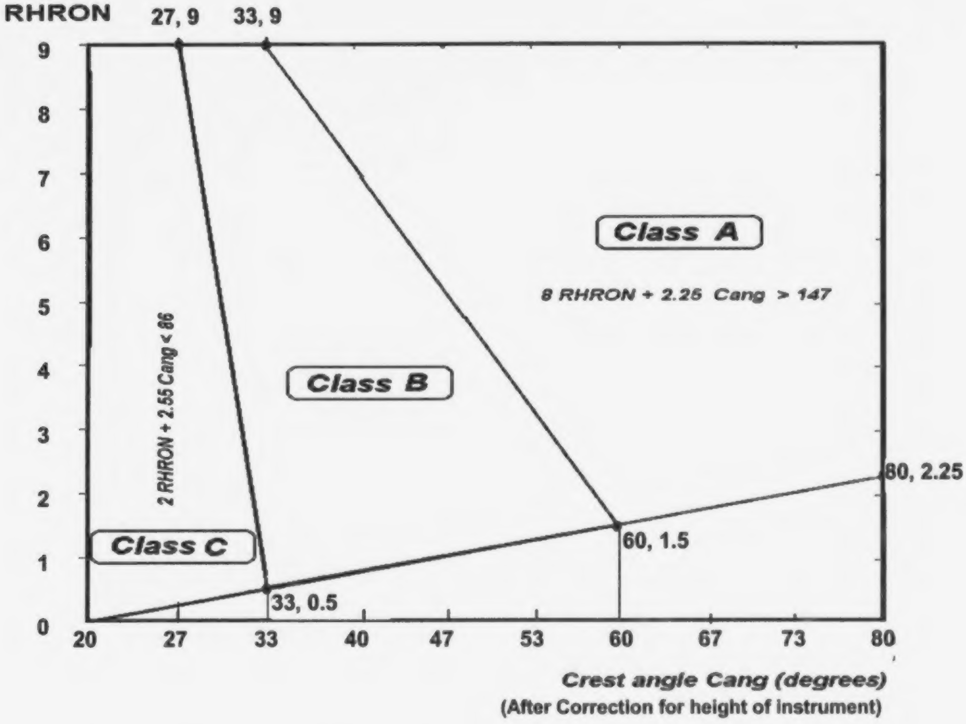

Figure 5 –Hazard Class Rating Chart

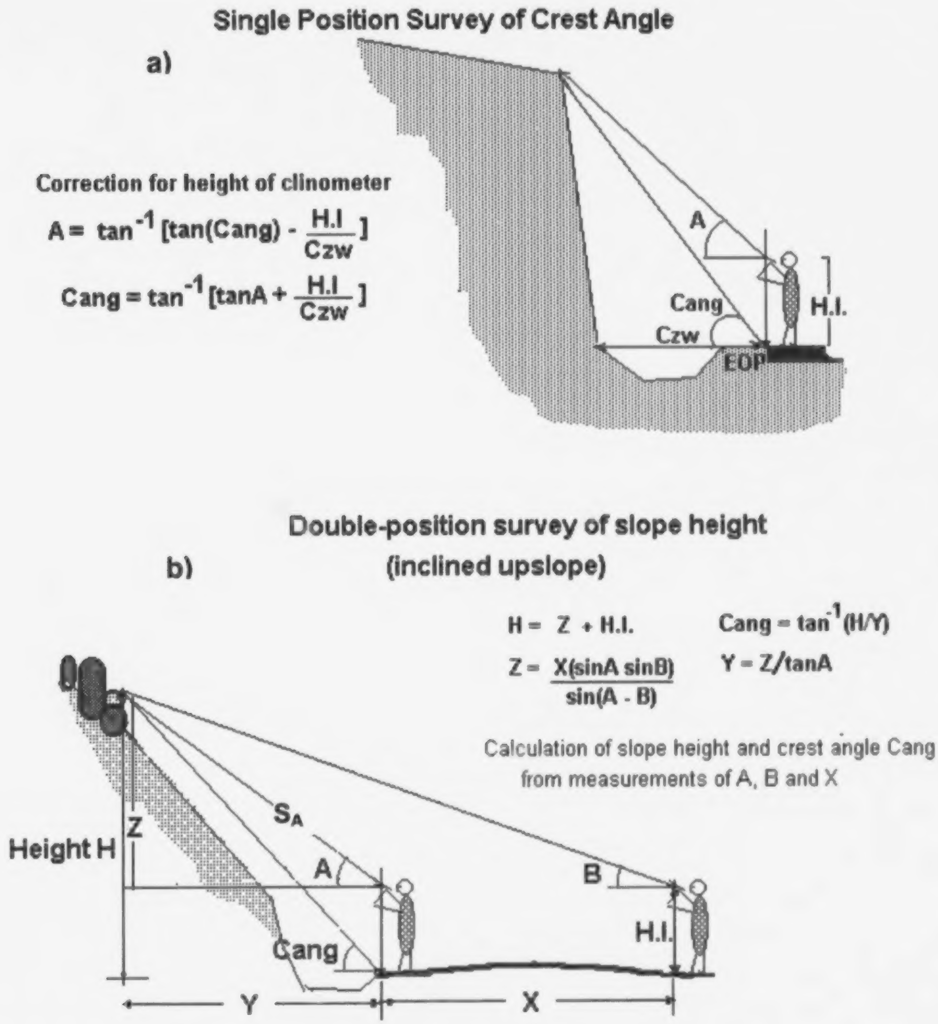

Figure 6 - Measurement of Crest Angle

SEGMENT		1	2	3	4	5	6	7	8	SITE#: Hwy:		
Start segment m										Direction: Side:		
End segment m										LHRS: Offset:		
Length of segment m										ΣLhaz m:		
Digital image, # & times										GPS Waypoint number:		
ROCKFALL TYPE AND QUANTITY Stable, Adequate ditch, Raveling, Overhang, Ice-jacking, Block [single], 2D Wedge, Pyramid, Toppling												
Mechanism										V2 Qmax Maximum fall m^3:		
Quantity Qtot m3										V3 ΣQtot Total falls m^3:		
SITE GEOMETRY AND GPS COORDINATES										UTILITIES		
Offside angle (B)										Type	Side	Offset
Nearside angle (A)												
Slope distance (S)										POSITIVE SITE ID?		
Paved width (X)										Yes / No		
Height m										V12 Height (worst seg):		
Czw m										V14 Czw (worst seg):		
PROPOSED METHOD(S) AND UNIT COSTS OF REMEDIATION										POCKMARKS (circle quantity)		
(preliminary assessment for prioritization only) Quantities per segment										Many	Some	None
TRIMMING AND REGRADING (To reduce F1 magnitude factor by ___ % = REMX1)											Total	
Hoe Ram	crew-hr.											
Backhoe Exc	crew-hr.											
Trim blast	m drilled											
Control blast	cu. m.											
STABILIZATION AND REINFORCEMENT (To reduce F2 instability factor by ___ % = REMX2)												
Rockbolts	each											
HT anchors	m drilled											
Drainholes	m drilled											
Shotcrete	sq. m.											
Mesh	sq. m.											
Straps	lin. m.											
CATCH, CONTROL & AVOIDANCE (To reduce F3 reach factor by ___ % = REMX3)												
Clean ditch	lin. m											
New ditch	lin. m.											
J. barrier	lin. m											
Catch fence	lin. m.											
Draped mesh	sq. m											
SIGNPOSTING, MONITORING ALARMS etc. (To reduce F4 consequences factor by ___ % = REMX4)											ΣREMX = 90%	
Fallen Rock	each											
WARNING POSTED		Yes	No	Paved Shoulder			Ditch Depth					
Continge = cost contingency multiplier											1.5	
Inspector's notes:												
Recommendations by: Date:												
RHRON FIELD DATA SHEET - SIDE 1												

Figure 7 - Field Data Sheet (Side 1)

SITE IDENTIFICATION		Hwy: Side:	SITE #:
Location: km N S E W of LHRS Basepoint:			
PARAMETER		VALUE V	RATING R
Identification	Detail		good bad
P1 Hist	History/evidence of falls	Rating only	0 1 2 3 4 5 6 7 8 9
P2 Qmax	Largest potential fall:	m^3	0 1 2 3 4 5 6 7 8 9
P3 Qtot	Total of potential fall/slides	m^3	0 1 2 3 4 5 6 7 8 9
P4 Firr	Face irregularity	m	0 1 2 3 4 5 6 7 8 9
P5 Loose	Face looseness (open joints)	Rating only	0 1 2 3 4 5 6 7 8 9
P6 Jop	Joint orientation-persistence	Rating only	0 1 2 3 4 5 6 7 8 9
P7 UCS	Uniax. compressive strength	MPa	0 1 2 3 4 5 6 7 8 9
P8 Phip	Shear strength	Peak friction angle ϕ_p °	0 1 2 3 4 5 6 7 8 9
P9 Block	Block size	cm	0 1 2 3 4 5 6 7 8 9
P10 Sdur	Slake-durability index (I_{d2})	%	0 1 2 3 4 5 6 7 8 9
P11 Wtab	Water table (% height of face)	%	0 1 2 3 4 5 6 7 8 9
P12 Height	Slope height (to highest hazard)	m	0 1 2 3 4 5 6 7 8 9
P13 Cang	Crest angle = $\tan^{-1}$(V12/V14)	°	0 1 2 3 4 5 6 7 8 9
Traffic Information	AADT		
	Posted speed	Psl km/h	
	Sight distance	m	
P15 Deff	Ditch effectiveness	Estimate %	0 1 2 3 4 5 6 7 8 9
P16 Ovsp	Ditch overspill potential	Estimate %	0 1 2 3 4 5 6 7 8 9
Rating by:		Date:	

Estimates for P1, P4, P5, P6, P7, P8, P15 and P16

P1, P4, P5, P6, P16		Deff		Firr
Term	Rating			
Ext Low	1	Ext Good	11	0.28
Very Low	2	Very Good	22	0.56
Low	3	Good	33	0.83
Mod Low	4	Mod Good	44	1.11
Moderate	5	Moderate	56	1.39
Mod High	6	Mod Poor	67	1.67
High	7	Poor	78	1.94
Very High	8	Very Poor	89	2.22
Ext High	9	Ext Poor	100	2.50

UCS (Mpa)	Rating	Base Phi	Phip
19	4	30	48
25	3.5	32	51
34	3	35	53
62	2	40	59
111	1	45	64
200	0	50	70

RHRON FIELD DATA SHEET - SIDE 2

Figure 7 - Field Data Sheet (Side 2)

R	V2 Qmax m^3	V3 Qtot m^3	V4 Firr m	V7 UCS MPa	V8 Phip °	V9 Block cm	V10 Sdur %	V11 Wtab %	V12 Height m	V13 Cang °	V14 Czw %	V15 Deff %	V16 Ovsp %	V17 Avr %	V18 Dsd %	V19 Apw m	V20 Remcost $CDN
0	1	1.0	0.00	200	70	200	80	0.0	0	20	120	0	0	0	120	16.0	1,000
1	1.3	1.7	0.28	111	64	120	71	11	3	27	110	11	11	11	111	14.9	2,100
2	1.6	2.8	0.56	62	59	72	62	22	7	33	100	22	22	22	102	13.8	4,600
3	2.2	4.6	0.83	34	53	43	53	33	10	40	90	33	33	33	93	12.7	10,000
4	2.8	7.7	1.11	19	48	26	44	44	13	47	80	44	44	44	84	11.6	21,500
5	3.6	13	1.39	11	42	15	36	55	17	53	70	56	56	56	76	10.4	46,400
6	4.6	21	1.67	5.8	37	9	27	67	23	60	60	67	67	67	67	9.3	100,000
7	6.0	36	1.94	3.2	31	6	18	78	23	67	50	78	78	78	58	8.2	215,000
8	7.8	60	2.22	1.8	25	3	9	89	30	73	40	89	89	89	49	7.1	464,000
9	10.0	100	2.50	1.0	20	2	0	100	30	80	30	100	100	100	40	6.0	1,000,000

Figure 8 - Conversion Table

TERMINOLOGY (RHRON Ratings and Formulae)

P =	Parameter, a property characterizing the degree of hazard;
V =	Value of the parameter, with units of measurement (e.g. lengths in metres);
T =	Truncated value for a parameter not allowed to exceed the limits of a permissible range;
R =	Rating derived from values or truncated values, normalized to give a range from 0 (good) to 9 (bad);
F =	Factor obtained by averaging a group of related ratings.

PARAMETER	TRUNCATION RANGE & UNITS	DETERMINATION OF VALUE	DETERMINATION OF RATING
P1 Hist History/evidence of falls	R1 [0 - 9]	Rating estimated directly	Estimated from maintenance reports and on-site evidence
P2 Qmax Largest potential fall	T2 [1-10 m3]	In-place volume	R2 = 9[log10(T2)]
P3 Qtot Total quantity of potential rockfall	T3 [1-100 m3]	In-place volume	R3 = 4.5[log10(T3)]
P4 Firr Face irregularity	T4 [0.0 - 2.5 m]	Visual estimate	R4 = 3.6(T4)
P5 Loose Face looseness	R5 [0 - 9]	Rating directly estimated	Estimate Rating from Figure 11
P6 Jop Joint orientation/ persistence	R6 [0 - 9]	Rating directly estimated	Estimate Rating from Figure 12
P7 UCS Intact strength	T7 [1-200 MPa]	Estimate Uniaxial Compressive Strength from Figure 13 a)	R7 = 9 - [3.911 x $\log_{10}$(T7)]
P8 Phip Shear strength Case 1: sliding unlikely (R6 < 7)	T8 [20° - 70°]	Estimate V8 from Figure 13 c)	R8 = 12.6 - 0.18(T8)
Case 2: sliding possible (R6 > 7) (no interlocking)	V8 [5° - 25°] T8 [20° - 25°]	V8 = ϕ_b based on mineral composition of filling given in Figure 13 b)	R8 9 8.5 8 ϕ_b < 20° 22° 25°
Case 3: Sliding possible (R6 > 7), interlocking rough thinly filled or weathered surfaces)	T8 [20° - 70°] at σ_n = 300 kPa	V8 = ϕ_b + 2JRC/ (1+3,000/JCS) (kPa units), JRC, JCS, ϕ_b from UCS given in Figure 13 a)	R8 = 12.6 - 0.18(T8)
P9 Block Block size	T9 [2 cm - 2 m]	V9 = D_{50} median dia.	R9 = 10.355 - [4.5 x $\log_{10}$(T9)]
P10 Sdur Slake-durability	V10 [0 - 100%] T10 [0 - 80%]	Estimate Slake-durability index I_{d2} from Figure 14. Check by testing (ISRM, 1981) if estimated V10 < 70%	R10 = 9 - (0.1125 x T10)
P11 Wtab Water table height	V11 [0 - 100%]	V11 = 100h/(V12) % % height of face	R11 = 0.09(V11)
P12 Height Slope height	T12 [0 - 30 m]	Estimate and check by clinometer or photo measurements	R12 = 0.3(T12)
P13 Cang Crest angle	T13 [20° - 80°]	See Figure 6	R13 = 0.15(T13) - 3
P14 Czw Clear zone width (ditch + shoulder)	V14 [30% - 120%]	V14 = 100 (Czw/Czwd) (%) measure Czw (m) with tape Czwd = f(SADT, Psl) from Figure 15	R14 = 12 – 0.1(V14)
P15 Deff Ditch effectiveness	V15 [0 - 100%]	V15 = Probability of any Qmax rock reaching the pavement (%)	R15 = 0.09(V15)
P16 Ovsp Overspill potential	V16 [0 - 100%]	Reach of Qmax as % width of pavement	R16 = 0.09(V16)
P17 Avr Average vehicle risk	T17 [0 - 100%]	V17(%) = (SADT x ΣLhaz) / (240 x psl)	R17 = 0.09(T17)
P18 Dsd Decision sight distance	T18 [40% - 120%]	V18 = (SD/DD) x 100% Psl 50 60 70 80 90 100 km/h DD 141 165 193 226 264 308 m	R18 = 13.5 - 0.1125(T18)
P19 Apw Available paved width	T19 [6 - 16 m]	V19 = nearside paved width (m) for a divided highway, otherwise full paved width	R19 = 14.4 - 0.9(T19)

P20 Remcost Remediation cost estimate	T20 [$1,000 - $1,000,000]	V20 = Costnet x Continge	$R20 = 3\log_{10}(T20) - 9$
F1 Magnitude	F1 (0-9)	Rating only	F1 = [R2+R3+R12]/3
F2 Instability	F2 (0-9)	Rating only	Ravelling mode F2 = [R1+R9+R11+R4+R5+R6]/6 Sliding mode F2 = [R1+R9+R11+R5+R6+R8]/6 Erosion mode F2 = [R1+R9+R11+R4+R7+R10]/6
F3 Reach	F3 (0-9)	Rating only	F3 = [R13+R14+(R15+R16)/2]/3
F4 Consequences	F4 (0-9)	Rating only	F4 = [R17+R18+R19]/3
RHRON Ontario Rock Hazard Rating			RHRON = (F1+F2+F3+F4)/4
COSTBEN Cost-benefit Rating			COSTBEN = 100(R20/ (RHRON x Remx%)
a) Main Formulae			

Slide volume estimation	Boulder: Cube D^3; Sphere $4/3\pi r^3 = 0.523\ D^3$ 2D wedge: (XYZ/2) sin(A-B) 3D pyramid: (XYZ/6) sin(A-B) where: X = crest length; Y = length of upslope dip line, Z = length of face dip line, A = face dip angle: B = upslope dip angle
Shale erosion undercut rates (cm/yr) (Shakoor & Rogers, 1992)	Urate cm/yr = 8.66 - 0.1717(Sdur) if Sdur <30% Urate cm/yr = 3.17 - 0.0137(Sdur) if Sdur >30% Urate cm/yr = 2.10 - 0.0119(Sdur) if Sdur >90%
Barton shear strength criterion as reformulated by Maksimovic (1996)	$\tau = \sigma_n \tan \phi_p$ $\phi_p = \phi_b + 2JRC/(1+ 10\sigma_n/JCS)$ where ϕ_p = peak friction angle; Phip = ϕ_p at σ_n = 300 kPa τ = shear strength of the joint (kPa); σ_n = component of stress normal to the joint (kPa)
b) Miscellaneous Formulae	

Figure 9 - RHRON Ratings and Formulae

R4 Firr Rating	Length of Half-Barrels / Length of blastholes	Average thickness of shotcrete to give a locally smooth face	Maximum depth (m) of overhangs Ohg / undercuts Uct / launching features LF
0	100%	< 10 cm	< 0.2 m
1	80%	< 10 cm	< 0.2 m
2	60%	< 10 cm	< 0.2 m
3	40%	< 10 cm	< 0.2 m
4	20%	0 - 10 cm	< 0.2 m
5	< 10%	10 - 20 cm	< 0.5 m
6	< 10%	20 - 30 cm	< 0.5 m
7	< 10%	> 30 cm	0.5-1 m
8	< 5%	> 30 cm	1 - 1.5 m
9	< 5%	> 30 cm	1.5 - > 2 m

Figure 10 - Estimation of Rock Face Irregularity

R5 LOOSE	Abundance of Joints at Maximum Aperture in Area 10 x 10 m	Typical Apertures	Face condition
0-2	1 - 10	0 - 1 mm	Tight, can be chipped only by machine
3-5	10 - 30	1 - 5 mm	Moderately loose, readily scaled by machine
6-7	30 - 50	2 - 15 mm	Very loose, easily scaled by hand
8-9	>50	>15 - 50 mm	Precarious stability, collapses on touch

Figure 11 - Estimation of R5 Face Looseness

R6 JOP	Trace Length	Dip Towards Face	Strike relative to Crest
0-2	1-3 m	< +20°	> 20°
3-5	3-5 m	+20° - +40°	10° - 20°
6-7	5-10 m	+40° - +60°	5° - 10°
8-9	>10 m	> +60°	0° - 5°
R6 is the average of separate estimates for trace length, dip and strike			

Figure 12 - Estimation of R6 Joint Orientation/Persistence

Geological Material	UCS (kPa)	JCS (kPa)	ϕ_b	FIELD IDENTIFICATION (ISRM, 1981)
Very soft clay	< 25	n/a	Minerals Table	Very soft and highly plastic
Soft clay	25 - 50	n/a	minerals table	Easily penetrated by thumb
Firm clay	50 - 100	n/a	minerals table	Penetrated several cm by thumb with moderate effort
Stiff clay	100 - 250	n/a	minerals table	Readily indented by thumb but penetrated only with great effort
Very stiff clay	250 -500	5 - 10	minerals table	Readily indented by thumbnail
Hard clay, Extremely weak rock	500 - 1,000	10 - 200	24°– 25°	Indented with difficulty by thumbnail
Very weak rock	1,000 -5,000	200 - 2,000	25° – 27°	Crumbles under firm blows with hammer, peeled with knife
Weak rock	5,000 -25,000	2,000 - 15,500	27° – 28°	Difficult to peel with knife, shallow indents by firm blow with point of gological hammer
Medium strong rock	25,000 - 50,000	15,500 - 35,500	28° – 29°	Cannot be scraped or peeled with a knife, fractured with single firm blow of hammer
Strong rock	50,000 - 100,000	35,500 - 80,000	29° – 30°	Requires more than one blow of hammer to fracture
Very strong rock	100,000 - 250,000	80,000 - 230,000	30° – 31°	Specimen requires many hammer blows to fracture
Extra strong rock	>250,000	> 230,000	> 31°	Specimen can only be chipped with hammer

a) Intact Strength, UCS/JCS and Base Friction Angle, ϕ_b

FILLING MINERAL TYPE	ϕ_b
Grp = graphite, black; Mic = mica, silver/black	12-16°
Clys = clay, smectite (highly plastic)	5-10°
Clyk = clay, kaolinite (plastic white)	12-15°
Clyi = clay, illite (moderately plastic, brown)	16-22°
Fe = iron stain, limonite, rusty or yellowish brown	20°
Tal = talc, white, soapy	20°
Chl = chlorite (green, soft)	20-30°
Ser = sericite, silvery, shiny	23°
cal = calcite, white/clear, can scratch	24°
py = pyrite vein	25°
mn = manganese, black-brown	25°
brc = hard breccia, weathered or softened surfaces	25°
qz = quartz, hard	25°

for unfilled or slightly weathered joints, use:
$\phi_b = 2.5 \log_{10}(Ucs) + 17.5$ (kPa units)

b) Base Friction Angle ϕ_b for Joint Filling Minerals

DISCONTINUITY DESCRIPTION	Approximate JRC	Approximate Phip
Thick soft gouge or multiple seams (shear zone)	0	20°
Thick mod. hard gouge, clay/graphite, slick	2	25°
Paper smooth, planar, non-polished	4	30°
Paper-smooth, slightly wavy, sandy or no fillings	6	35°
Slightly rough, may contain thin medium-strong fillings e.g. calcite, chlorite, with slight loss of interlocking	8	40°
Moderately smooth, slaty texture, wavy	10	45°
moderately rough, sandy texture, wavy	12	50°
coarse gravelly texture,irregular	14	55°
coarse saw-tooth texture wavy	16	60°
very rough, may contain hard fillings e.g. quartz	18	65°
jagged and stepped, fully interlocking	20	70°

for hazard rating purposes only: for sliding stability analyses, determine shear strength using $\tau = \sigma_n \tan \phi_p$
where $\phi_p = \phi_b + 2jrc/(1+10\sigma_n/jcs)$

c): Joint Roughness Coefficient JRC and Shear Strength Index Phip

Figure 13 - Estimations of Rock (or Infilling) Strength

R10 Sdur	$V10 = I_{d2}$	Description of typical material and behaviour
0	>95%	Hard silty argillite, durable, does not soften when wetted. Also most non-shale rock types
0	80%	Silty mudstone or similar, moderately durable
1	71%	Some bed separation during 1-2 months of exposure
3	53%	Disintegrates during 1-2 months exposure
5	36%	Disintegrates during 1-2 weeks exposure
7	18%	Disintegrates during 1-2 days exposure
9	0%	Smectite clay-shale, disintegrates during 1-2 hours of exposure
Based on behaviour of freshly removed samples at natural water content R10 = 9 - (0.1125 T10)		

Figure 14 - Estimation of R10: Sdur – Slake Durability Index

Psl (km/h) / AADT	70	80	90	100	110	120
≥ 6,000	4	5	6	7	9	10
≥ 1,500	3	4	5	6	7	8
< 1,500*	3	4	4	5	6	7

The data given above is from the Ministry of Transportation's Roadside Safety Manual (1993).

*** The"Low Design Value" is intended to minimize collisions with the rock, not to provide rock catch capacity**

R14 Czw	V14 Clear zone width	Designation
0	120%	Oversize clear zone
2	100%	Full clear zone
4	80%	Moderate clear zone
6	60%	limited clear zone
8	40%	Very limited clear zone
9	30%	Extremely limited clear zone
V14% = 100 x (Czw/Czwd) R14 = 12 - 0.1(V14)		

Figure 15 - Designations for R14: Czwd – Clear Zone Width Low Design Values

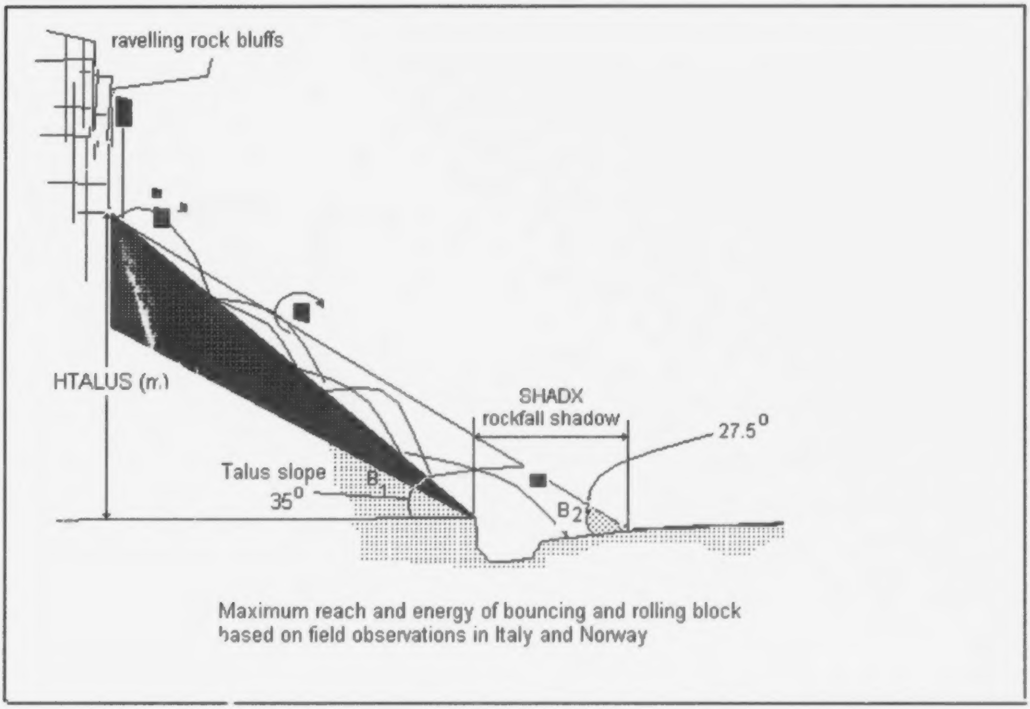

Figure 16 - Dynamic Blockfalls and Catchfence Design

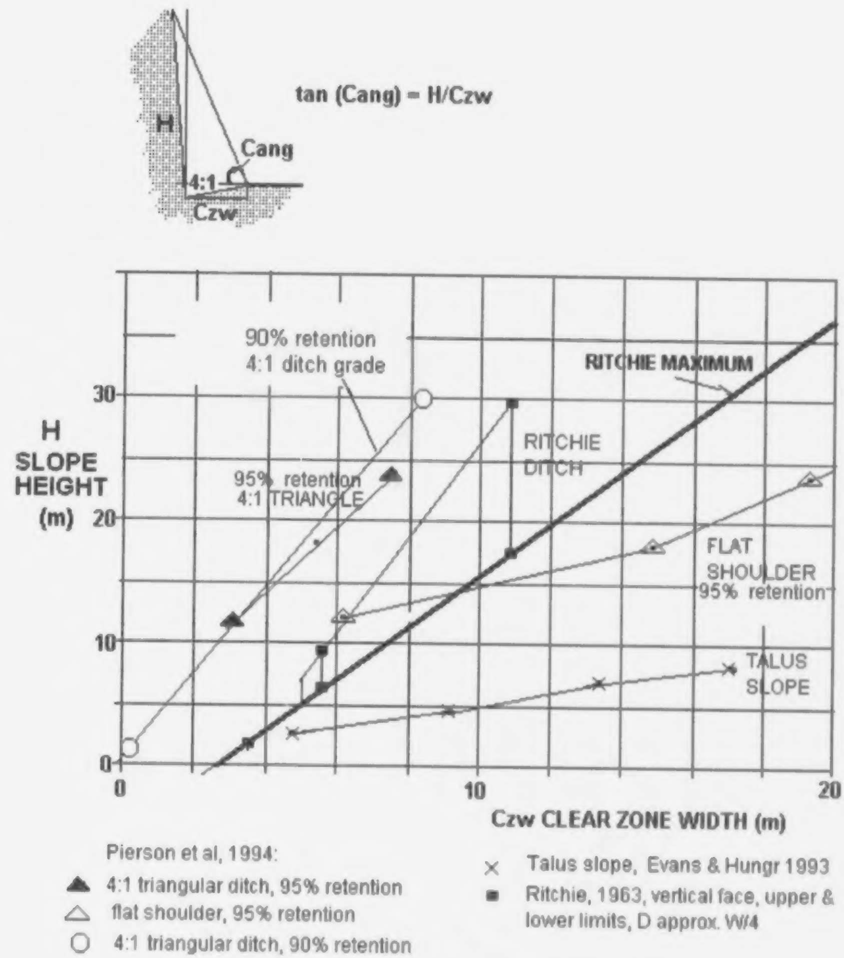

Figure 17 – Ditch Design

APPENDIX 3

Alternative Crest Angle Determination / Supplementary Joint Information

A3.1 ALTERNATIVE DETERMINATION OF CREST ANGLE

Crest angle, Cang, is defined above as the upward angle from EOP to the highest potentially unstable rock. For most normal conditions, Cang is measured to the crest of the slope. For cases where face geometry can be approximated as a near-vertical rock face with no upslope hazard, the single position survey method shown in Figure 6a can be used to estimate Cang. Obviously measurements of true Cang from pavement level are neither safe nor practical. Readings are therefore taken from eye level and corrected for height of instrument using the equations in Figure 6.

An alternative is to use a macro embedded in Excel that takes the measurements and corrections and outputs the crest angle.

The correction values shown below in Figure A.3-1 are based on an instrument height of 1.6 m but can be used with little error for eye levels in the range 1.4 to 1.8 m. Note that the amount of correction depends both on A and Czw. Hardly any correction is needed for steep high faces (i.e. A = 70° to 80°) with a wide clear zone. A modest correction is needed for most rock faces of intermediate height, whereas the correction increases rapidly (i.e. up to 29°) for low-angle slopes as A approaches 20°.

Corrections can be interpolated, e.g. for the case A = 55°, Czw = 4.5 m, identifying the nearest data in the table gives a correction of about 6° for a Cang value of 61°:

The crest angle for a vertical slope can also be calculated from the formula given in Figure 6a:

$$\text{Cang} = \tan^{-1}[\tan A + (HI/Czw)]$$

$$\tan 55° = 1.428;\ HI/Czw = 1.6/4.5 = 0.355$$

$$\text{Cang} = \tan^{-1}[1.783] = 60.7° \text{ (rounded to } 61°)$$

A table of reverse corrections, from true to measured angle, is given in Figure A.3-2. This allows use of the clinometer or a simple sighting device in order to check whether Cang exceeds a given critical value. These corrections are tabulated both for eye level 1.6 m (on-foot readings) and 1.1 m (eye level from a small car).

Measured crest angle: A	Clear Zone Width: Czw (m)					
	2	3	4	5	6	7
	Height of Instrument Correction (^{0}) (add to measured crest angle A to obtain true crest angle: Cang)					
20^{0}	+29	+22	+17	+14	+12	+10
40^{0}	+19	+14	+11	+9	+8	+7
60^{0}	+8	+6	+5	+4	+3	+3
80^{0}	+1	+1	+1	+1	+0	+0

Correction for Height of Clinometer
Obtained from: Cang = tan-1[tan(A) + (HI/Czw)]
(HI assumed to be 1.6 m)

Figure A.3-1 - Correction Values for an Instrument Height of 1.6 m

Required true crest angle: Cang	Clear Zone Width Czw (m)					
	2	3	4	5	6	7
	Clinometer readings corresponding to the required true crest angles					
Angles measured from vehicle (HI = 1.1 m) in °						
20^0	-	-	5	8	10	12
27^0	-	8	13	16	18	19
Angles measured standing on EOP (HI = 1.6 m) in °						
27^0	-	1	6	11	14	16
33^0	-	7	14	18	21	23
40^0	2	17	24	27	30	31
60^0	43	50	53	55	56	56
80^0	78	79	79	79	80	80
A = tan-1[tan(Cang) - (HI/Czw)]						

Figure A.3-2 - Conversion from true to measured crest angle.

A3.2 SUPPLEMENTARY JOINTING DATA

Estimate and record these supplementary data only if sliding instability appears possible (typically about 10% of cases) and is to be analyzed. The properties should then be measured rather than estimated. They are not used directly in RHRON, but are employed in estimation of "Jop" and "Phip" ratings and for preliminary stability calculations. These values therefore are not converted to Ratings.

A3.3 PERSISTENCE AND TRACE LENGTH

A natural fracture or joint is visualized as being made up of un-bonded, very weak segments and rock bridges that are as strong or almost as strong as the intact rock material. Persistence is the ratio of the un-bonded area to the total area in the plane of the joint. The property can also be estimated in terms of maximum trace lengths visible in the rock face.

A3.4 STRIKE AND DIP

For rating purposes, joint azimuth (dip and strike) are estimated relative to the direction of the slope crest and not with relative to true north which is the method usually used.

Strike is defined relative to the strike of the crest and ranges from zero for joints striking parallel to the crest (i.e. the least stable condition, favouring planar sliding) to 90° (i.e. the most stable condition).

"Dipmag" is the magnitude of the dip in a vertical plane perpendicular to the slope crest. This factor may range from +0° (horizontal) to +90° then back to -0°. A "+" value indicates a daylighting direction (where the joints dip less steeply than the slope face) and "-" value indicates dip into the face (i.e. the most stable condition).

A3.5 FILLING TYPE AND THICKNESS

Filling type relates to the "filling mineral types" listed in Figure 13b. Use the abbreviations given, or record "Clean" where the joints are unfilled. Estimate filling thickness in millimetres or record "Trace" when less than 0.5 mm.

A3.6 INTERLOCKING JOINT SURFACES AND $Ø_p/Ø_b$

Record whether the joint surfaces are "interlocking" (yes or no). An interlocking joint has a filling thickness less than the roughness amplitude and has not been pre-sheared. Pre-sheared joints (i.e. faults or shears) can generally be recognized by shiny, striated surfaces ("slickensides") or by the presence of breccia, gouge or mylonite.

Record "ϕ_p" (i.e. Phip) using information from Figure 13c when the joints are interlocking or "ϕ_b" (i.e. base friction angle) from Figure 13b when they are not.

A3.7 ROUGHNESS

Estimate the roughness amplitude as the maximum gap (mm) between a 10 cm straightedge and the joint surface. Average about five measurements at different locations on the joint surface. Estimate waviness in the same manner using a 1 m straightedge. Estimate the approximate Joint Roughness Coefficient (JRC) from Figure 13b. When required for stability analyses, a more reliable estimate can be obtained by tilt testing or shadow profilometry. The strength reduction factor "F" relates the joint surface compressive strength (JCS) to that of the intact material, UCS, as defined in subsection 4.4.3. Estimate a value from 1.0 for clean unweathered joints to 0.25 for weathered and weakened joint surfaces.